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C-Band Airport Surface Communications System Standards Development

Phase II Final Report

Volume 2: Test Bed Performance Evaluation and Final AeroMACS Recommendations

Edward Hall and James Magner
ITT Corporation Electronic Systems, Fort Wayne, Indiana

April 2011

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Preface

This National Aeronautics and Space Administration (NASA) Contractor Report summarizes and documents the work performed to develop system standards for the proposed C-band (5091- to 5150-MHz[1]) airport surface communications system. The report consists of two volumes. Volume I is devoted to Concepts of Use, Initial System Requirements, and Architecture and includes AeroMACS Design Considerations. Volume II describes Test Bed Evaluation and presents Final AeroMACS Recommendations.

This work was completed under the NASA Aerospace Communication Systems Technical Support (ACSTS) contract, based on direction provided by the Federal Aviation Administration project-level agreement (PLA FY09_G1M.02-02v1) for “New ATM Requirements—Future Communications” as a follow-on to the FAA/EUROCONTROL (European Organisation for the Safety of Air Navigation) Cooperative Research Agreement (Action Plan 17 (AP−17)), commonly referred to as the Future Communications Study.

[1]With a possible future extension into the 5000- to 5030-MHz band, pending a decision at the World Radiocommunications Conference in 2012.

Executive Summary

ES.1 Introduction

This report is being provided as part of the NASA Glenn Research Center Aerospace Communication Systems Technical Support (ACSTS) Contract (NNC05CA85C), Task 7: "New ATM Requirements—Future Communications, C-Band and L-Band Communications Standard Development."

Task 7 is separated into two distinct subtasks—each aligned with specific work elements and deliverable items identified in the Federal Aviation Administration's (FAA) project-level agreement (PLA) and with the FAA fiscal years 2009 and 2010 New ATM Requirements—Future Communications Project and spending plan for these subtasks.

The purposes of subtask 7–1 and the subjects of this report are the definitions of the concepts of use (ConUse), high-level system requirements, and architecture; the performance of supporting system analyses; the development of test and demonstration plans; and the establishment of operational capability in support of C-band aeronautical data communications standards to be advanced in both international (International Civil Aviation Organization, ICAO) and national RTCA, Inc. (RTCA) forums.

The future C-band (5091 to 5150 MHz[1]) airport surface communication system is referred to as the Aeronautical Mobile Airport Communications System (AeroMACS).

Assumptions and constraints for this report follow:

- The 5091- to 5150-MHz spectrum allocation for AeroMACS use at the World Radiocommunications Conference (WRC–2007) is provisioned only for use on the airport surface. This allocation is within the aeronautical mobile (route) service (AM(R)S) band. Therefore, AeroMACS applications are constrained to mobile applications on the airport surface. This is interpreted to include communications for nonmobile (i.e., fixed) applications provisioned within a mobile AeroMACS network that supports the safety and regularity of flight.
- The proposed AeroMACS is assumed to provide an increase in overall air-to-ground (A/G) communications systems capacity by utilizing the new spectrum (i.e., in addition to existing very high frequency (VHF) spectrum).
- The scope of this ConUse and requirements report includes airport surface A/G communications and ground-to-ground (G/G) communications.
- AeroMACS will be designed specifically for data communication. Voice communication may be provided as a digital data communications service (e.g., voice over internet protocol (VoIP)).
- This report assumes that the data communications system developed as part of the FAA Data Communications Program (Data Comm) will precede an A/G AeroMACS implementation and deployment.
- Although some critical services could be supported, AeroMACS networks will also target noncritical services, such as weather advisory and aeronautical information services implemented as part of an airborne access to System Wide Information Management (SWIM) program.
- AeroMACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the C-band. Additional interference research and testing will determine if any operational constraints are to be imposed, such as limiting the number of users, the time of the day, the duration, and so on.

Volume I of this report is devoted to the concepts of use, system requirements, and architecture, and the second volume addresses the test bed architecture and performance evaluation and presents final AeroMACS recommendations from the tests.

The decision to base airport surface communications on WiMAX was based on the IEEE 802.16e–2005 mobility amendment to the IEEE 802.16 standard. The IEEE 802.16e–2005 amendment and additional new amendments have since been incorporated into the IEEE 802.16 standard to form the more inclusive IEEE 802.16–2009 standard that remains backward-compatible with the mobility amendment.

References to the standard will be stated as IEEE 802.16–2009 in this report unless the discussion is specifically in reference to IEEE 802.16e for historical or format reasons.

ES.2 Introduction to Volume II

Volume II describes modifications to the NASA Glenn/Cleveland Hopkins International Airport (NASA–CLE) Communications, Navigation, and Surveillance (CNS) Test Bed to add Institute of Electrical and Electronics Engineering (IEEE) 802.16–2009 (Ref. 1) capability. Test and evaluation results from simulation, emulation, and test bed measurements are presented. It also provides initial data to be input to the aeronautical mobile-specific IEEE–2009 design specifications.

Developing an AeroMACS solution based on the IEEE 802.16–2009 standard requires detailed analysis, simulation, and test measurements on actual airport surfaces. An AeroMACS test bed aids in validating requirements and acts as a prototype deployment. Such a CNS test bed has been installed and is operational at NASA Glenn and the adjacent CLE Airport in Cleveland, Ohio. This so-called NASA–CLE CNS Test Bed, originally developed by the Sensis Corporation via a cooperative agreement with Glenn, has been modified by ITT to implement many of the AeroMACS features and requirements that support modern data communications at an operational airport to help verify the performance of AeroMACS and validate some of the ConUse.

Figure ES–1 shows the placement of the AeroMACS network on NASA Glenn property and the adjacent CLE airport surface.

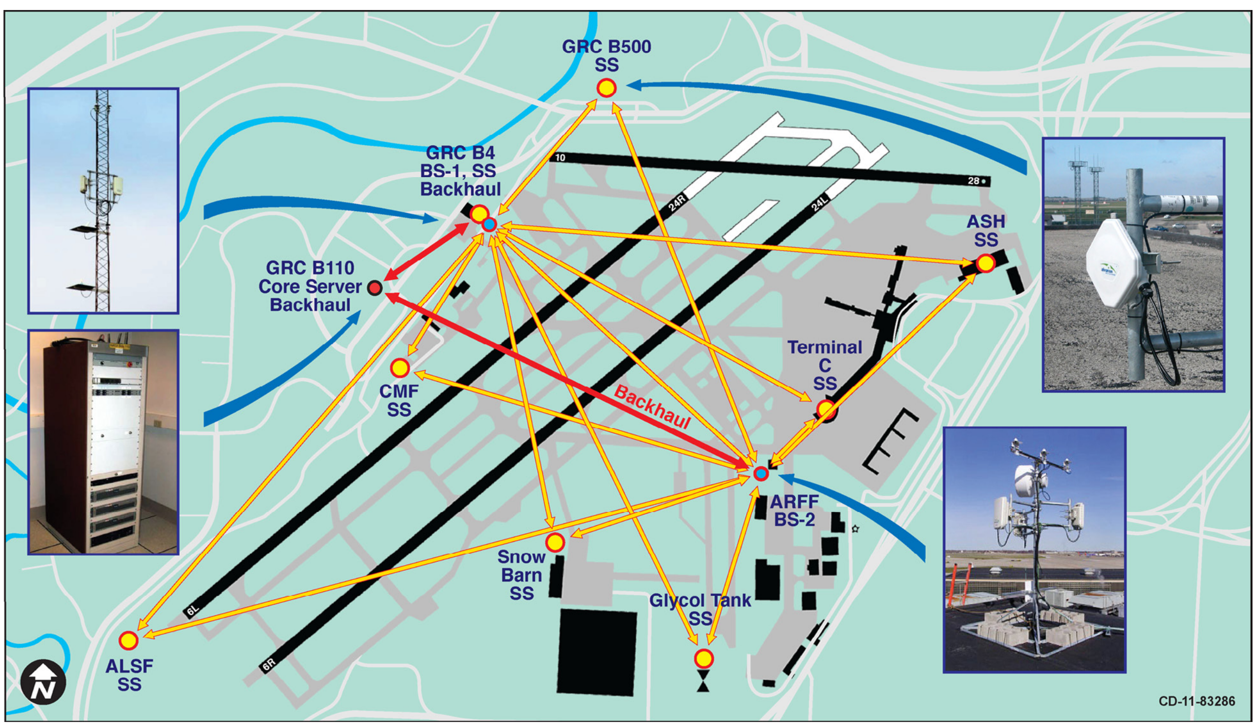

Figure ES–1.—AeroMACS prototype network base station, backhaul, and core server locations. Acronyms are defined in Appendix A.

The AeroMACS prototype network uses two base stations (BSs): one on Glenn property (Building 4) and another on airport property on top of the Aircraft Rescue and Fire Fighting (ARFF) building. The BS on Glenn property includes two base transceiver station (BTS) sectors, and the BS on CLE property contains three BTS sectors. These BSs are linked to core servers located in Glenn Building 110 by microwave data backhaul radios operating outside of the AM(R)S spectrum. Fixed-location subscriber stations (SSs) are located at two positions on Glenn property (Buildings 4 and 500) and six positions on airport property. Tests are planned that will include mobility with vehicle- and aircraft-mounted SSs.

Expected AeroMACS link performance for fixed-position SSs was analyzed using the Cellular Expert analysis program developed by HNIT–BALTIC.[2] Results are shown in Figure ES–2 on the basis of highest achievable modulation rate across the airport surface. Except for where links are physically shadowed by obstructions, the analysis predicts that the highest data throughput modulation rate supported by the IEEE 802.16–2009 standard will be achieved across a significant majority of the airport surface. The boresight orientation of the BTS sectors at each BS is indicated by the white arrows in Figure ES–2.

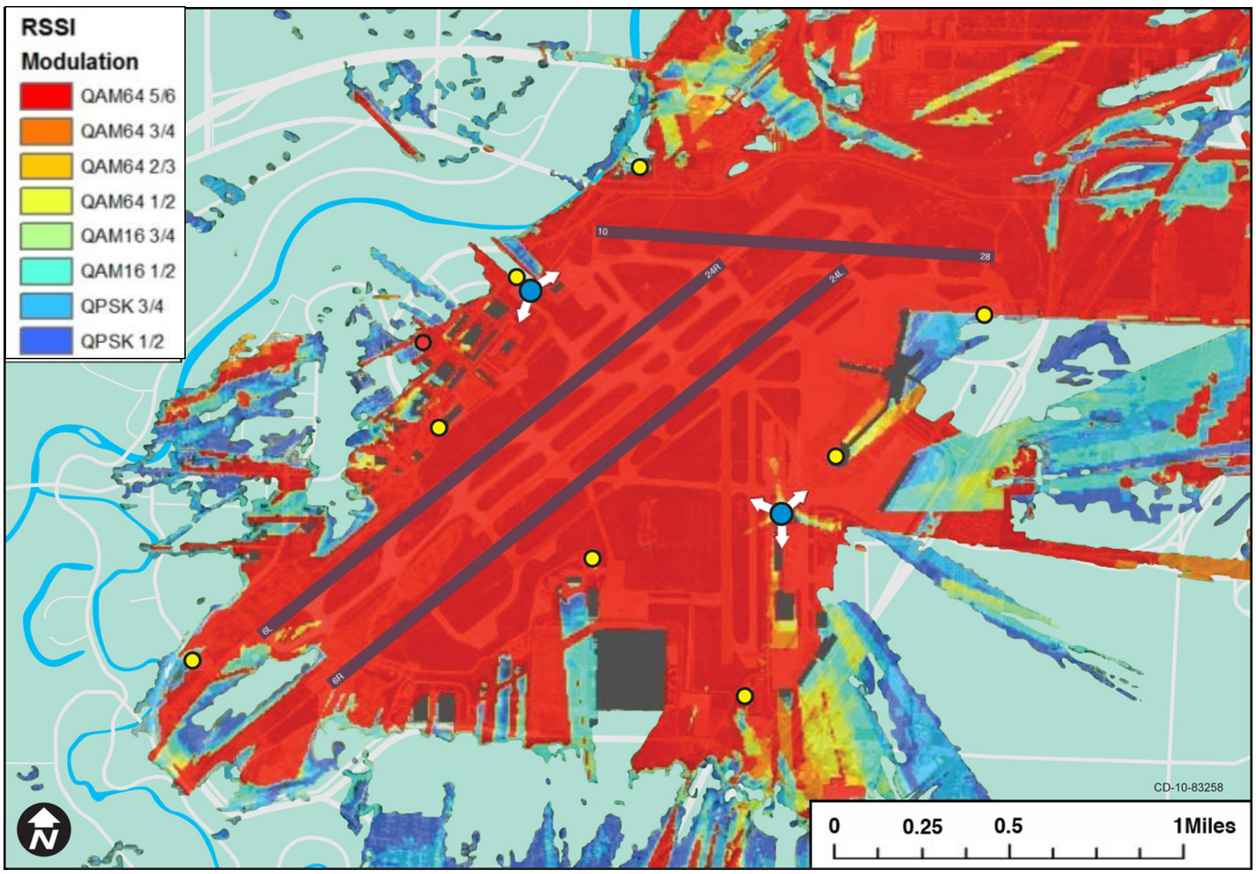

Figure ES–2.—Received signal strength indication (RSSI) plot for 17-dBi directional subscriber station mounted at 12 ft. Acronyms are defined in Appendix A.

[2]http://www.hnit-baltic.lt/.

Evaluation of the IEEE–802.16–2009-based AeroMACS prototype network can be grouped into two sets of tests:

(1) Baseline performance tests within the Phase I project scope
(2) A set of tests designed to support development of an aviation profile and to evaluate the support of FAA applications

ES.3 Network Evaluation

Two sets of AeroMACS network tests were completed using the NASA–CLE CNS Test Bed. The first set, completed in early 2010 in Task 7-1 Phase I, collected baseline network performance soon after the AeroMACS prototype network was added to the test bed. Eleven network tests were defined to establish the basic operating capability of the IEEE–802.16–2009-based capability that was added to the NASA–CLE CNS Test Bed. The tests establish operating capability in the following areas of network operation:

- Security with authentication and encryption
- Data throughput and channelization
- Quality of service (QoS) data prioritization
- Mobility at motor vehicle speeds
- Reliability during extended operation

The operational integrity of the AeroMACS test bed was verified using the 11 baseline tests defined in Section 3.1 according to hardware capability. The tests that involve mobility (test cases 9 and 10) were not completed because the hardware available during Phase I could not support mobility handover operation. Results from the remaining tests provided a deeper understanding of AeroMACS capability and were used to guide development of the Phase II test plan.

Initial network performance data were collected to assess the data throughput capacity of links between the SS at NASA Glenn Building 500 and the two BTS sectors located at NASA Glenn Building 4. Test data streams were generated by Ixia Chariot[3] software hosted on the single-board computers (SBCs) at each end of the link. The results shown in Table ES–1 are for the downlink (DL: BS to SS) and the uplink (UL: SS to BS) directions. The measured throughput exceeded the manufacturer's estimated rates in all cases.

The second set of test plans and results are for work completed under Phase II of contract Task 7-1. The Phase II tests are designed to refine AeroMACS network profile requirements and to demonstrate AeroMACS utility in handling applications.

TABLE ES–1.—AEROMACS NASA–CLE TEST BED LINK TEST RESULTS
[Acronyms are defined in Appendix A.]

BTS sector	Measured DL throughput, Mbps	Expected DL throughput, Mbps	Measured UL throughput, Mbps	Expected UL throughput, Mbps
BTS1_1	6.82	6.5	5.4	4.0
BTS1_2	6.54	6.5	4.19	4.0

[3]http://www.ixiacom.com.

A test plan was established for Task 7-1 Phase II that governs testing in areas that are important for establishment of an AeroMACS network profile. The following four tests are included:

(1) Test Case 1, Multilateration (MLAT) Surveillance Communications
(2) Test Case 2, AeroMACS Mobility Test
(3) Test Case 3, Channelization Tests
(4) Test Case 4, Transmit Power Requirements

Test Case 1, MLAT Communications.—The initial evaluation of AeroMACS support of MLAT used live data flows from each of the eight MLAT sensor sites. The AeroMACS network carried this traffic to a central processor in Glenn Building 110 for surveillance data processing and graphical target display by Sensis equipment.

A quantitative assessment of AeroMACS network support of MLAT traffic was completed by using IxChariot test software to generate MLAT-like traffic flows. IxChariot was used to collect statistics of traffic flow, sometimes with live MLAT traffic also flowing through the network simultaneously. No impact was observed in the IxChariot performance statistics when live MLAT traffic feeds were active.

IxChariot posttest analysis provided time latency information for the MLAT-like traffic. Traffic latency statistics for this test were

- Average = 67 ms
- Minimum = 47 ms
- Maximum = 73 ms

Packet latency was nearly identical for the higher priority MLAT-like traffic whether or not the serving BS sector was overloaded with lower-priority traffic assigned best effort (BE) QoS.

The evaluation of MLAT system support by an AeroMACS network included nonquantitative analysis with live MLAT traffic processed by Sensis equipment for graphical displays of aircraft positions, and quantitative assessments using software generated traffic of the packet size and rate used for MLAT but with no recorded or simulated MLAT information in the data packets. AeroMACS network support for MLAT should be further evaluated in the future to provide a complete assessment of potential performance impact to support an investment decision for provision of MLAT-based surveillance services over an AeroMACS.

Test Case 2, AeroMACS Mobility Test.—A series of tests evaluated the ability of a mobile AeroMACS SS to support communications under a variety of conditions.

- Mobile at speeds of at least 40 kt
- Single antenna and antenna diversity modes including single-input, single output (SISO) and multiple-input, multiple-output (MIMO) modes
- Mobility within BS sectors and across BS regions requiring service handover

A series of mobile AeroMACS drive tests were conducted using the NASA Aeronautical Research Vehicle (ARV) at the Cleveland Hopkins (CLE) airport on runway 24L/6R on October 12, 2010. Drive speed was nominally 40 kt (about 46 mph or 74 km/h). Tests were conducted with the mobile SS antenna system set in either the MIMO or SISO mode.

The position of runway 6R/24L relative to BS1 and BS2 is shown in Figure ES–3. Sector antenna pointing directions are indicated by arrows for the BTS sectors (two for BS1 and three for BS2). The BTS sector antennas have a 90° half-power (3 dB) beamwidth. The approximate 3-dB boundaries are indicated in Figure ES–3 with dashed lines for the two sectors used most often in these tests, BTS 1-2 and BTS 2-3. The ARV, travelling along runway 24L in the southwest (SW) direction, will experience varying signal levels from a combined effect of range changes and BS sector antenna gain variation as the aspect angle changes.

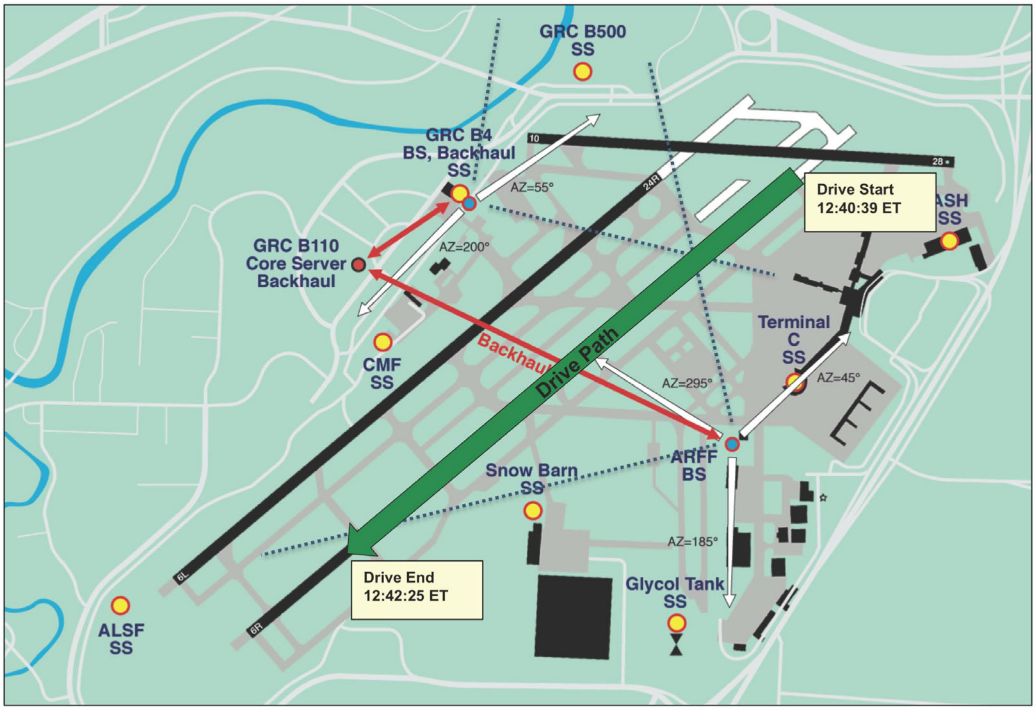

Figure ES–3.—NASA ARV drive test, Runway 24L; ARV position VS time (GMT); Speed = 40 kt (46 mph, 74 km/h); Oct. 12, 1640 GMT. Acronyms are defined in Appendix A.

A plot of DL throughput during an ARV drive test along runway 24L from northeast (NE) to SW is shown in Figure ES–4. Results for MIMO and SISO antenna modes are plotted. A comparison of traffic throughput rate averaged over the length of the drive test for MIMO and SISO antenna modes is summarized in Table ES–2.

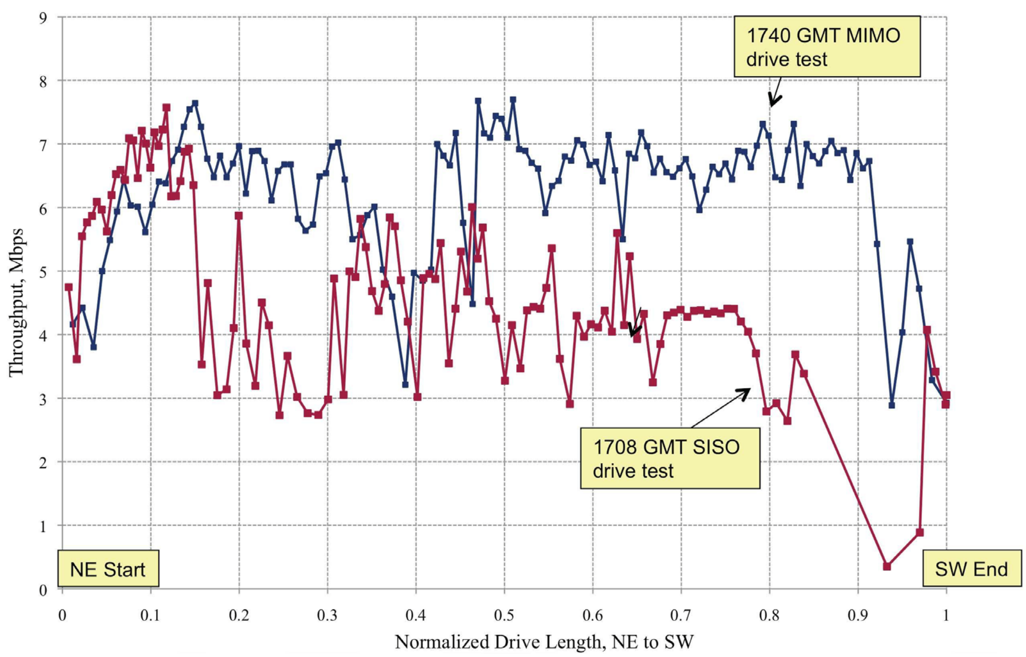

Figure ES–4.—NASA ARV drive test, Runway 24L; DL throughput along drive path, Mb/s; Speed = 40 kt (46 mph, 74 km/h); MIMO and SISO antenna mode comparison; 1640 GMT MIMO, 1708 GMT SISO. Acronyms are defined in Appendix A.

TABLE ES–2.—MIMO AND SISO MOBILE ANTENNA CONFIGURATION THROUGHPUT COMPARISON
[Acronyms are defined in Appendix A.]

Test time	Antenna mode	Throughput average, Mbps	Throughput minimum, Mbps	Throughput maximum, Mbps
1640 GMT 10/12/10	MIMO	5.13	2.70	7.70
1708 GMT 10/12/10	SISO	3.89	0.35	7.57

Test Case 3, Channelization Tests.—The goal of the channelization tests is to evaluate the need to allocate a guard band between AeroMACS channels to prevent adjacent-channel interference that will reduce channel throughput. The between-channel guard band would be in addition to the guard band implemented in the IEEE 802.16–2009 standard by suppression of subcarriers at the channel edges.

Adjacent channel interference performance was aided by BS sector antenna rejection factor that is to be expected in an operational network layout. A small (2 percent) traffic throughput rate change was observed when an active adjacent channel was present. This reduction presumably impacts both of the adjacent channels. The observable impact was lessened to 1 percent when the second channel was moved 10 MHz away. These results support a decision that no allocation of additional guard band between AeroMACS channels to suppress adjacent-channel interference will be included in AeroMACS profile recommendations.

Test Case 4, Transmit Power Requirements.—The transmit power level requirements were studied through a series of drive tests with the mobile ARV SS. Transmit power levels must be chosen to provide communication coverage across an airport surface while also minimizing potential interference to co-allocated users of the 5091- to 5150-MHz band.

The operating conditions of the NASA Glenn AeroMACS prototype in Cleveland provided DL throughput rate of at least 3 Mbps for a range of approximately 1 mile (1.6 km) for the following conditions:

- Clear line of sight from BS2 to ARV SS on runway 24L
- BTS sector transmit power: +20 dBm (100 mW) per MIMO channel
- BTS sector: 2×2 MIMO, mode A
- ARV SS: 2×1 MIMO, mode A
- BTS sector antenna gain: +16 dBi
- ARV SS antenna gain: +8 dBi

This test established that a minimum of 3-Mbps traffic throughput rate can be established over the intended cell radius of 1.6 km with 100 mW BTS transmitter power under benign link conditions. Additional tests and analysis need to be completed in future work to assure that this power level provides suitable performance on links into areas of higher signal multipath and non-line-of-sight conditions, such as closer in toward the terminals and gate.

ES.4 AeroMACS Specification Profile Recommendation Process

National Airspace System (NAS) growth and improvement will provide continued safety, efficiency, and reliability to the flying public. The AeroMACS solution is designed to help increase airports' capacity for departures and arrivals, as well as enhance the safety and efficiency of surface movement, improve the security and flexibility of airport surface operations, and increase the situational awareness for airport surface users and stakeholders. AeroMACS will also help reduce delays, fuel consumption, and emissions. Finally, an AeroMACS profile will be developed in cooperation with the European Organisation for the Safety of Air Navigation (EUROCONTROL) to advance the establishment of global standards and interoperability to effectively and efficiently enable rapid and thorough airport improvements as new applications augment and replace legacy systems.

ES.4.1 RTCA SC–223 for AeroMACS Standards Recommendations

Special Committee SC–223 was established within the RTCA aviation industry consortium to establish standards for AeroMACS. The principal products of this special committee are a set of system profile recommendations delivered in September 2010 and a minimum operational performance standards (MOPS) document to be delivered in December 2011 (Ref. 2). The European Organisation for Civil Aviation Equipment (EUROCAE) established a parallel work group, WG–82, that is chartered to develop an AeroMACS profile for use in Europe that is interoperable with the AeroMACS profile developed by RTCA. SC–223 and WG–82 are working cooperatively to develop a common profile document that will be provided as recommendations for consideration by ICAO.

Sets of system parameter profiles have been recommended for AeroMACS within this study. These profiles areas are based on the existing IEEE 802.16–2009 standard. System profile parameter values were selected within the IEEE 802.16–2009 standard to maximize the reuse of the published Worldwide Interoperability for Microwave Access (WiMAX) profile and commercial, profile-compliant, off-the-shelf hardware and software. In addition, AeroMACS profile parameter options are included that give the future operational system designer flexibility to accommodate the applications and environment that will be unique to each airport. Table ES–3 summarizes key parameter selections for the five profile areas that are defined in the IEEE 802.16–2009 standard and that are recommended for an AeroMACS standard profile. The five profile areas listed in the table correspond to the five profile areas that distinguish mobile WiMAX profiles. A working group within RTCA SC–223 is tasked with further developing the AeroMACS profile to decide whether parameters are mandatory or optional to implement in an operational AeroMACS deployment.

TABLE ES–3.—SUMMARY OF FINAL RECOMMENDATIONS FOR AEROMACS PROFILE

Profile area	Key parameter selections
Radiofrequency and radio parameters	
Frequency band, MHz	5091 to 5150
Channel bandwidths, MHz	5 with 10 for future consideration
Channel center frequencies	See Table 20
Power class	
Maximum downlink transmitter (Tx) power	Unchanged from IEEE 802.16–2009
Maximum uplink Tx power	Unchanged from IEEE 802.16–2009
Duplex mode—time-division duplex (TDD) or frequency-division duplex (FDD)	TDD
Physical layer	Performance profiles—minimum performance defined in IEEE 802.16(e) and
M-ary quadrature amplitude modulation (QAM) range	Table 17 for 5-MHz channels Table 18 for 10-MHz channels
Coding options	
Multiple input, multiple output (MIMO)	
Media Access Control (MAC) layer	All parameters unchanged from IEEE 802.16–2009
Automatic repeat request	
Security protocols	
Mobile protocols	
Quality-of-service (QoS) options	
Mesh options	

ES.4.2 WiMAX Forum AeroMACS Ad-Hoc Working Group

A technical parameter profile has been developed for AeroMACS that is patterned after the WiMAX Forum Mobile System Profile Specification developed for commercial mobile WiMAX systems. The AeroMACS profile is based on the WiMAX Forum Mobile System Profile: Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02) document (Ref. 3) that was developed and is maintained by

the WiMAX Forum. A joint RTCA and WiMAX Forum ad hoc working group has been established to develop an AeroMACS profile that is consistent with WiMAX Forum documentation and processes.

An AeroMACS profile ensures that all stakeholders—test equipment vendors, integrated circuit vendors, as well as the aviation industry—are capable of supporting the AeroMACS development and that a deployment will be globally interoperable. A profile will be used as a guide for development of a MOPS document within RTCA SC–223.

WiMAX Forum profiles are referenced in the IEEE 802.16–2009 standard in three main parts: COMMON, TDD, and FDD.

The recommended AeroMACS is a TDD-only system so the third part of the WiMAX Forum profile will not be used. AeroMACS will be based on Release 1.0 profile because it is presently the only release certified by the WiMAX Forum for use by industry. Release 1.5 has been approved but not implemented for hardware certification because the IEEE 802.16m amendment is expected to be implemented soon with profile Release 2.0. The RTCA SC–223 and EUROCAE WG–82 decided jointly not to implement features of profile Release 2.0 at this time because that release of the WiMAX standard is still in development.

ES.4.3 AeroMACS Profile Development Status

An AeroMACS profile has been developed through a series of RTCA and EUROCAE meetings and telephone conferences. SC–223 and WG–82 leadership participated in all plenary meetings of each other's organizations. An ad hoc joint committee was established between RTCA SC–223 and the WiMAX Forum in August 2010. A joint RTCA and EUROCAE meeting was held in Brussels, Belgium, in late October 2010 with participation by members of the WiMAX Forum via telephone conference in which many profile parameter settings were established for AeroMACS. A fully harmonized profile was established during the RTCA SC–223 Plenary Meeting #8 in November 2010. This harmonized profile is available on the RTCA SC–223 Workspace site[4]. The profile document is based on the WiMAX Forum Release 1.0 profile and includes a rationale statement for the setting chosen for each parameter.

The joint AeroMACS profile completed in December 2010 is the RTCA "final draft" version. EUROCAE will continue their studies in 2011, leading to a "final joint profile" by the end of 2011 that may differ from the 2010 final draft profile based on results of the EUROCAE studies. EUROCAE plans to complete validation tests before publishing a final AeroMACS profile by the end of 2013.

[4]Available at http://workspace.rtca.org/kws/my_account Access permission is required.

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1.0 Introduction

1.1 Background

During the past five years, the NASA Glenn Research Center (Glenn) and ITT Corporation have conducted a three-phase technology assessment for the Federal Aviation Administration (FAA) under a joint FAA–European Organisation for the Safety of Air Navigation (EUROCONTROL) Cooperative Research Action Plan (AP–17), also known as the Future Communications Study (FCS). NASA Glenn, with the contracted support of ITT, provided a system engineering evaluation of candidate technologies for the future communications infrastructure (FCI) to be used in air traffic management (ATM). Specific recommendations for data communications technologies in the very high frequency (VHF), C-, L-, and satellite bands, and a set of follow-on research and implementation actions have been endorsed by the FAA, EUROCONTROL, and the International Civil Aviation Organization (ICAO). In the United States, the recommendations from AP–17 are reflected in the Joint Planning and Development Office's (JPDO) "Next Generation Air Transportation System, Integrated Plans" (Ref. 4) and are represented in the "National Airspace System (NAS) Infrastructure Roadmaps" (Ref. 5).

Action Plan 30 (AP–30), a proposed follow-on cooperative research to AP–17, ensures coordinated development of FCI to help enable the advanced ATM concepts of operation (ConOps) envisioned for both the Next Generation Air Transportation System (NextGen) in the United States and EUROCONTROL's Single European Sky ATM Research (SESAR) program in Europe. Follow-on research and technology development recommended by ITT and NASA Glenn and endorsed by the FAA was included in the FAA's NextGen Implementation Plan 2009. The plan was officially released at the NextGen Web site (http://www.faa.gov/about/initiatives/nextgen/) on January 30, 2009. The implementation plan includes a FY09 solution set work plan for C-band and L-band future communications research in the section, "New Air Traffic Management (ATM) Requirements."

On February 27, 2009, the FAA approved a project-level agreement (PLA FY09_G1M.02-02v1) for "New ATM Requirements—Future Communications," to perform the FY09 portion of the FAA's solution-set work plan; this includes the development of concepts of use (ConUse), requirements, and architecture for both a new C-band airport surface wireless communications system and a new L-band terrestrial en route communications system. On February 1, 2010, the FAA approved the follow-on PLA (FY10_G1M02-02) to provide findings and recommendations to the RTCA and EUROCAE WG-82 on the aviation profile of the IEEE-802.16e (WiMAX)-based standard for an aeronautical mobile airport communications system (AeroMACS), and to complete evaluation of a proposed L-band digital aeronautical communications system (L–DACS) in relevant environments to support new en route ATM requirements. The work described in this report covers ITT's portion of the PLA tasks related to C-band airport surface wireless communications development. The L-band portions of the PLA research are documented in a companion report.

This report is being provided as part of the NASA Glenn Contract NNC05CA85C, Task 7: "New ATM Requirements—Future Communications, C-Band and L-Band Communications Standard Development." Task 7 is separated into two distinct subtasks, each aligned with specific work elements and deliverable items identified in the FAA's project-level agreement and with the FAA FY09 and FY10 spending plan for these subtasks. The purpose of subtask 7–1, and the subject of this report, is to define the C-band airport surface ConUse, systems performance requirements, and architecture in a future C-band (5091 to 5150 MHz[5]) air-to-ground (A/G) communication system referred to as the Aeronautical Mobile Airport Communications System (AeroMACS). The work is being performed in two phases. This report builds on Phase I results and is provided as a Phase II deliverable.

[5]With a possible future extension into the 5000- to 5030-MHz band, pending a decision at the World Radiocommunications Conference in 2012.

This Volume II document describes Phase II work to validate performance AeroMACS requirements and candidate architecture through test and evaluation of an AeroMACS prototype network built by ITT in the NASA Glenn Test Bed. A description of the AeroMACS prototype network is provided, followed by descriptions and results of tests that evaluate AeroMACS performance using the prototype network. Final AeroMACS standards recommendations are provided.

1.2 Document Overview

This document is organized as follows:

- Section 1.0 provides background system information and describes the document scope, organization, and references.
- Section 2.0 describes modifications to the NASA Glenn/Cleveland Hopkins International Airport (NASA–CLE) Communications, Navigation, and Surveillance (CNS) Test Bed to add Institute of Electrical and Electronics Engineering (IEEE) 802.16–2009 surface wireless communications network capability, referred to as the AeroMACS prototype, and testing and evaluation results using simulation, emulation, and/or prototype testing. It also provides initial data to be input to the aeronautical IEEE 802.16–2009 design specifications for AeroMACS.
- Section 3.0 presents the AeroMACS prototype network evaluation performed for this project, including a test plan description and associated test results.
- Section 4.0 provides initial inputs to an aeronautical IEEE 802.16–2009 design specification, referred to as the AeroMACS profile.
- Section 5.0 provides concluding requirements and specification recommendations for use by standards-setting bodies.
- Appendix A defines acronyms and abbreviations used in this report.
- Appendix B defines a test plan for tests using the NASA–CLE CNS Test Bed for the development of AeroMACS standards.

2.0 AeroMACS Prototype Performance Evaluation

2.1 Prototype Architecture

The AeroMACS architecture is based on the WiMAX Forum definitions that are outlined in Volume I of this report. Design of an AeroMACS prototype network requires detailed analysis and simulation as well as test measurements on candidate airport surfaces. Experimental measurements carried out on candidate airport surfaces can provide sufficient data to calibrate key performance tradeoffs that will be modeled by computer simulations. One or more mobile subscriber stations (SSs) are included in the prototype experiments to assess the downlink (DL: transmission from BS to SS) and the uplink (UL: SS to BS) performance coverage for initial measurements related to mobile operation.

2.1.1 Prototype Test Objectives

The prototype testing provides quantitative data to aid in the installation of the first phase of an IEEE 802.16–2009-based AeroMACS network at other airports of similar complexity. Specific objectives include the following:

- Assess the full range of AeroMACS profile options for the physical (PHY) and medium access (MAC) layer specification, and recommend initial values for each parameter in the profile.
- Verify functional operation of the PHY and MAC layers within the recommended profile.
- Obtain measurements at various locations on the airport surface to calibrate coverage models for the UL and DL systems.
- Measure multichannel performance with sectored BS antennas to support BS location analysis.
- Validate operation of AeroMACS while supporting applications with IP-based communications.

In addition, data collected from the prototype testing at a specific airport location can be analyzed relative to other experimental data from airport measurements. This helps to reinforce conclusions and uncover inconsistencies.

2.1.2 Prototype Test Approach

To meet the testing objectives, two BSs were utilized that have overlapping coverage on the airport surface. In addition, fixed and mobile SSs were utilized to obtain UL and DL coverage data and to evaluate parameter settings under a variety of conditions.

An AeroMACS prototype network having these considerations and conforming to the architecture described in Volume I has been implemented in the NASA–CLE CNS Test Bed. The physical installation is described in the following sections.

2.2 AeroMACS Prototype Implementation

The AeroMACS prototype implemented within the NASA–CLE CNS Test Bed is designed to provide many of the features required to support data communications at an operational airport. The commercial WiMAX equipment installed in the AeroMACS prototype is based on the Alvarion BreezeMAX product line and modified by Alvarion to ITT's specifications to allow experimental operation in the 5091 to 5150 MHz band. Two BSs are included in the AeroMACS prototype to provide coverage redundancy and at least two opportunities for an SS to link with a BS. Multiple base transceiver station (BTS) sectors are implemented at each BS to increase link sensitivity and data capacity. The network includes access service network–gateway (ASN–GW) and connectivity service network (CSN) functions, defined in Volume I, Section 6.8, to provide quality of service (QoS) control, user authentication and authorization for security, and mobility handoff between multiple BTS sectors.

This section describes the AeroMACS prototype hardware and network layout that is implemented in the NASA–CLE CNS Test Bed. Many of the decisions about network layout in Cleveland at NASA

Glenn and CLE were driven by the need to use readily available mounting structures for the BS and SS sites, the desire to integrate with already-determined Test Bed sensor sites, and the fact that this network is intended for test purposes and does not interact with airport operations.

The design process and system tradeoffs that would be used to design an operational deployment at an airport are discussed in Volume I of this report. Each fixed SS installation in the prototype includes an IEEE–802.16–2009-compliant radio transceiver and integrated antennas in a sealed weatherproof outdoor unit (ODU), as well as separate weatherproof enclosure that includes a single-board computer (SBC), a managed Ethernet switch, and power supplies to enable performance testing and applications demonstrations. The SBC hosts a Linux operating system and Ixia Chariot software for network performance tests. The Chariot software generates test data streams that are used to test communication link capabilities. A test console is located at the core server in NASA Glenn Building 110 to coordinate the execution of tests, collect Chariot test results through the network, and compute statistics of network performance. Existing airport sensors, such as the MLAT surveillance remote units previously installed by the Sensis Corporation through a cooperative agreement with NASA Glenn, can be connected as live data sources in place of, or in addition to, the Chariot software test data streams. A port on the managed switch is the interface for IP-based sensors such as the Sensis MLAT sensors.

Figure 1 shows the placement of the two AeroMACS prototype BS sites and their sectorized coverage in the NASA–CLE CNS Test Bed. The BS mounted on the tower adjacent to NASA Glenn's Flight Research Building (Building 4) hangar office has two BTS sectors that are directed 55° and 200° azimuth from "true north." The Aircraft Rescue and Firefighting (ARFF) building located on CLE airport property has three BTS coverage sectors directed 45°, 185°, and 295° from true north. The coverage area of each sector is 90° in azimuth as determined by the –3-dB pattern rolloff of the BTS sector antenna. These sector-coverage placements provide a high degree of redundant coverage across the desired coverage area, including the runways, most of the taxiways, and much of the ramp areas.

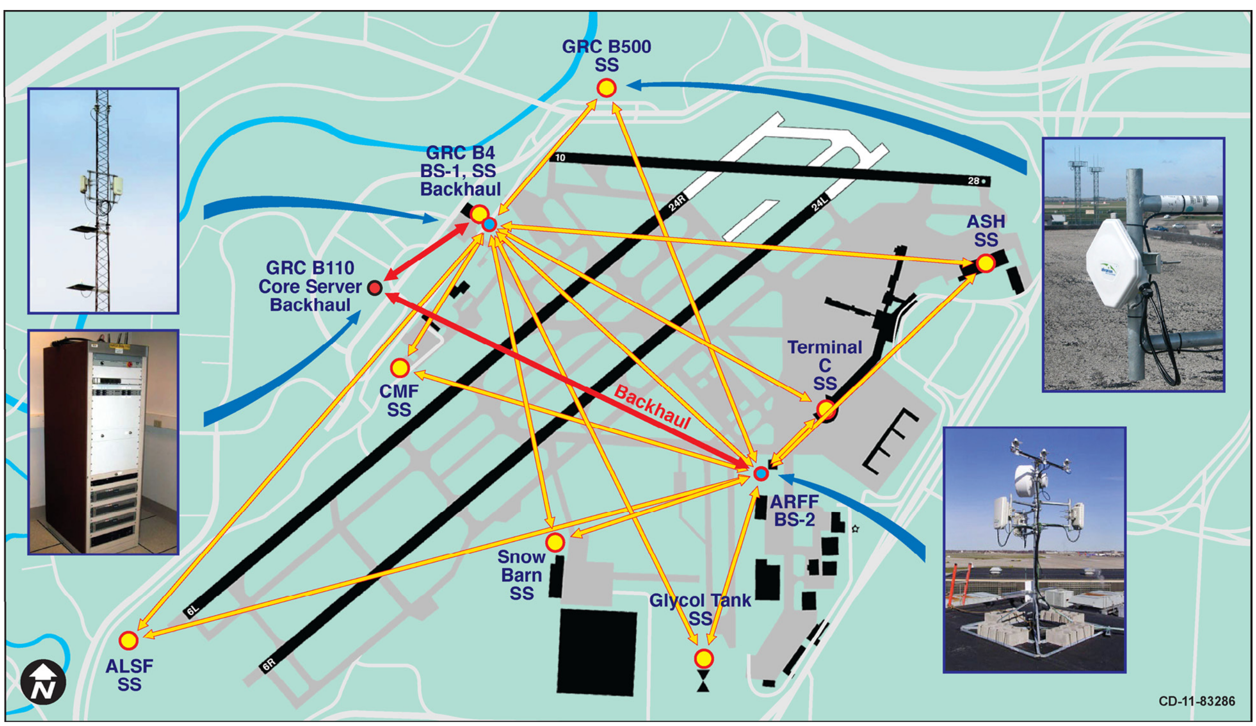


Figure 1.—NASA–CLE CNS Test Bed base station, backhaul, and core server locations. Acronyms are defined in Appendix A.

Figure 2 shows the placement of SSs at eight fixed sites. Each of these sites was chosen for its co-location with the Sensis MLAT surveillance sensor equipment already present in the test bed. Each SS can be used to wirelessly transport MLAT data to a central surveillance data processor located within the test bed. Each fixed SS has direct line-of-sight (LOS) to both BSs using directional antenna coverage.

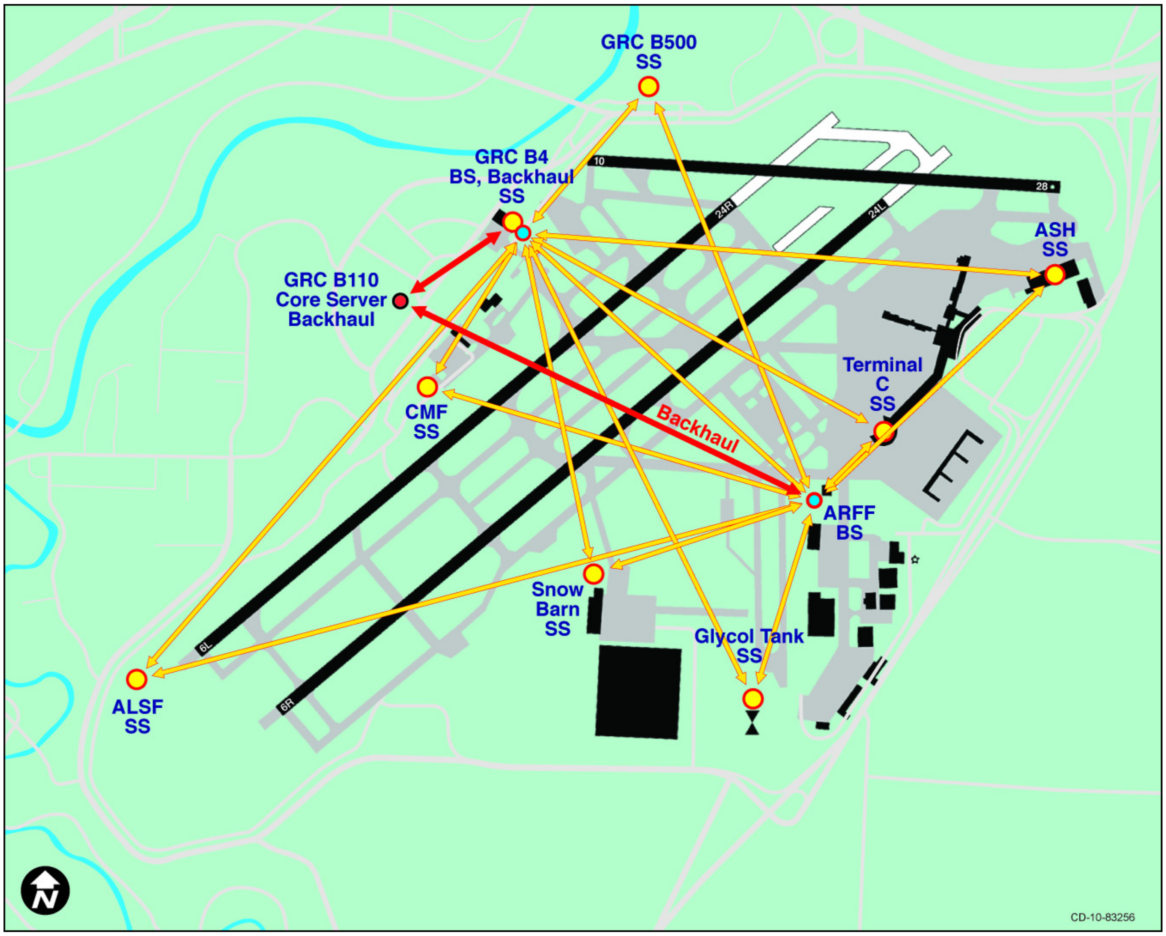


Figure 2.—NASA–CLE CNS Test Bed subscriber station locations and links. Acronyms are defined in Appendix A.

Data from each BS site is transported to the core server using wireless backhaul links that operate in a licensed 11-GHz commercial band. A pair of these microwave radios is used on the roof of NASA Glenn's Building 110 (Space Experiments Lab) in full duplex operation between each BS site and the core CSN servers located in Building 110. Table 1 shows the frequency assignments for the data backhaul radios.

TABLE 1.—BACKHAUL RADIOFREQUENCY ASSIGNMENTS
[Acronyms are defined in Appendix A.]

Transmitter data radio location	Receiver data radio location	Frequency assignment, MHz
CLE ARFF building	NASA Glenn Building 110	10 915.0
NASA Glenn Building 4	NASA Glenn Building 110	10 795.0
NASA Glenn Building 110	NASA Glenn Building 4	11 285.0
NASA Glenn Building 110	CLE ARFF building	11 405.0

Each SS installation includes the IEEE–802.16–2009-compliant radio transceiver, an SBC, a managed Ethernet switch, and power supplies in a weatherproof enclosure. The SBC hosts a Linux operating system and Ixia Chariot software for network performance tests. The Chariot software generates test data streams that are used to test communication link capabilities. A test console located at the core server in NASA Glenn's Building 110 coordinates the execution of the tests, collects Chariot test results through the network, and computes statistics of network performance. The test setup can be reconfigured to use data streams from airport sensors, such as the MLAT surveillance remote units, instead of Chariot software test data streams. A port on the managed router is the interface for IP-based sensors.

As described earlier in this section, five BTS sectors are used in the AeroMACS prototype to provide wide airport surface coverage and a high degree of link redundancy. The transceiver supporting each coverage sector is given a frequency channel assignment. Sector channel bandwidths are selectable to be 5- or 10-MHz, with 20-MHz available in a future firmware upgrade.

Sectors having overlapping surface coverage are placed on different channels to avoid co-channel interference. Reuse of channel assignments is possible for larger-area airport surface deployments where not all sectors have overlapping coverage. Deployment of the AeroMACS prototype network within the NASA–CLE CNS Test Bed is expected to initially use five channels; one per sector, spaced at 5 or 10 MHz centers across the 5091- to 5150-MHz spectrum allocation to avoid co-channel interference.

Center frequency options for the five channels are set using the AeroMACS radionfrequency (RF) profiles defined in Table 2. The WiMAX radios are programmable for either 5- or 10-MHz channel bandwidths and may be upgradable to have a 20-MHz channel bandwidth option in the future, although 20-MHz is not under consideration for AeroMACS. Prototype test bed BTS center frequencies are varied according to test parameter setup requirements.

TABLE 2.—NASA–CLE CNS TEST BED 5-MHz CHANNEL FREQUENCY ASSIGNMENT OPTIONS

5-MHz channel	Lower frequency, MHz	Center frequency, MHz	Upper frequency, MHz
1	5092.5	5095	5097.5
2	5097.5	5100	5102.5
3	5102.5	5105	5107.5
4	5107.5	5110	5112.5
5	5112.2	5115	5117.5
6	5117.2	5120	5122.5
7	5122.5	5125	5127.5
8	5127.5	5130	5132.5
9	5132.5	5135	5137.5
10	5137.5	5140	5142.5
11	5142.5	5145	5147.5

Channel frequency assignment options available for 10-MHz channel bandwidths for the five sectors of the NASA–CLE CNS Test Bed are listed in Table 3. The 10-MHz bandwidth option does not allow five channels to be fit in the 5091- to 5150-MHz range so frequency reuse will be required for 10-MHz channels and the five BTS sectors. Actual frequency assignments will vary according to test objectives and will be set on a per-test basis as needed.

TABLE 3.—NASA–CLE CNS TEST BED 10-MHz CHANNEL-FREQUENCY ASSIGNMENTS

10-MHz channel	Lower frequency, MHz	Center frequency, MHz	Upper frequency, MHz
1	5095	5100	5115
2	5115	5120	5125
3	5125	5130	5135
4	5135	5140	5145

C-band AeroMACS hardware units installed in the AeroMACS prototype at the two BS/BTS and eight fixed SS sites are shown in Figure 3. The BTS sector outdoor unit is highly integrated, with each outdoor unit containing two 90° by 8° sector-coverage antennas for second-order diversity operation and RF and digital circuitry for all radio and digital processing functions. The SS outdoor unit is similarly integrated, having two integrated high-gain antennas, C-band radios, and digital processing electronics.

Figure 3.—NASA Glenn AeroMACS prototype base transceiver station (BTS) and subscriber station (SS) outdoor units.

Second-order diversity operation is implemented in each AeroMACS transceiver in a multiple-input, multiple-output (MIMO) antenna configuration. Each BTS has 2×2 MIMO: two transmitters and two receivers operating in the transmit/receive TDD mode. Each transmitter/receiver pair is connected to one of the two internal antennas. The antennas operate in a cross-polarization mode so that two independent propagation paths are formed.

The prototype SS transceivers also have two built-in cross-polarized antennas. This case uses 2×1 MIMO: two receivers and a single transmitter are connected to the antennas to support diversity propagation paths.

The general specifications shown in Table 4 apply to the BTS and SS radios installed in the prototype. The radios operate in a TDD mode. The IEEE 802.16–2009 standard specifies adaptive modulation coding that sets eight different modulation levels from QPSK to 64–QAM, according to link conditions, in order to maximize data throughput rates for available signal quality. The standard specifies multicarrier orthogonal-frequency-division multiplexing (OFDM) modulation in the multiple access (OFDMA) mode which enables simultaneous data transfer from/to multiple applications through a single SS unit. Forward error correction (FEC) coding is adaptively set for coding rates between 1/2 (for QPSK) and 5/6 (for 64–QAM) to maximize the data throughput for the current link conditions.

TABLE 4.—GENERAL RADIO SPECIFICATIONS

Item	Description
Operation mode	Time-division duplex (TDD)
Modulation	Orthogonal-frequency-division multiplexing (OFDM) modulation, 1024/512 fast Fourier transform points, quadrature phase-shift keying (QPSK), 16 quadrature amplitude modulation (QAM), 64–QAM
Access method	Orthogonal-frequency-division multiple access (OFDMA)
Forward error correction (FEC)	Convolutional turbo coding: 1/2, 2/3, 3/4, and 5/6

Specifications for each single-sector BTS outdoor unit implemented in the NASA Glenn AeroMACS prototype are shown in Table 5. Each BTS outdoor unit is tunable over a wider frequency range than is needed for the present AM(R)S allocation of 5091- to 5150-MHz and supports operation in the 5000- to 5030-MHz segment if it is allocated for AeroMACS AM(R)S in a future World Radiocommunication Conference (WRC). Channel bandwidths can be set for 5 or 10 MHz in the initial AeroMACS prototype hardware, with a planned upgrade that would include 20-MHz channel bandwidth capability. The built-in antennas provide two high-gain directive patterns with orthogonal polarization to support dual-channel second-order diversity MIMO operation for improved link sensitivity. Operating frequency and channel bandwidth are controlled by configuration parameters that are set up in the CSN core server by the network operator. The five channel center frequencies used in the prototype are controlled by BTS frequency settings, and are varied according to test parameter setup requirements.

TABLE 5.—5100-MHz BASE TRANSCEIVER STATION SPECIFICATIONS

Frequency, MHz	4900 to 5350
Supported bandwidths, MHz	5 and 10 (20 after future expansion)
Transmitter (Tx) power range, dBm	0 to 21 (in 1-dBm steps)
Tx power accuracy, dB	± 1
Maximum input power (at antenna port), dBm	
Before saturation	–50
Before damage	–10
Diversity	Second order (multiple input, multiple output, MIMO)
Antenna pattern	15 dBi in the 4.9- to 5.9-GHz band for each diversity channel, 90° azimuth by 8° elevation sector antenna, dual-slant ±45° polarization
Height by width by depth, mm	510 by 280 by 147
Weight, kg	10.7
Power source, Vdc	40 to 60

Similar to the BTS outdoor unit, the SS outdoor unit is highly integrated with RF and digital electronics and a dual-polarization antenna in a single package. The antenna description is provided in Table 6. SS unit operating frequency, channel bandwidth, and transmit power level are all controlled by the BS it connects to upon entry into the AeroMACS network.

TABLE 6.—C-BAND SUBSCRIBER STATION SPECIFICATIONS

Polarization	Dual slant
Gain, dBi	17
Beamwidths	24° azimuth by 18° elevation

Mobility tests were conducted with an SS installed in NASA Glenn's Aeronautical Research Vehicle (ARV) shown in Figure 4. SS hardware modified to support an external antenna was installed. Link coverage was provided with a pair of antennas having omnidirectional azimuth coverage mounted on top of the ARV.

NASA Glenn's Viking S3 aircraft (Figure 5) or other research aircraft may be used for future mobility tests and demonstrations in an aircraft mobile environment. Future tests will be conducted while the aircraft is taxiing on the CLE airport surface and in the high-multipath-interference environment near the terminal gates. Again, modified SS hardware that supports the use of external antennas will be used.

Figure 4.—NASA Glenn’s mobile aeronautical research vehicle: ARV.

Figure 5.—Viking S–3 mobile platform.

2.3 Simulation, Emulation, Testing Results, and Evaluation

Evaluation of the C-band IEEE 802.16-based prototype AeroMACS network installed in the NASA–CLE CNS Test Bed consists of a study of system tradeoffs, link performance analysis, and performance test measurements of the installed network. This report presents an analysis of the prototype configuration layout shown in Figure 1 and Figure 2. The prototype network physical configuration was analyzed using the Cellular Expert analysis program developed by HNIT–BALTIC.

2.3.1 Network Simulation Evaluation Results

The Cellular Expert analysis program was used to predict AeroMACS performance for the NASA–CLE CNS Test Bed AeroMACS prototype installation. This tool can predict data throughput rates that are achievable for locations across the airport surface. The program utilizes the parameters of the IEEE 802.16–2009 hardware and the radio signal propagation properties, which are affected by antenna mounting heights, ground terrain profiles, and shadowing caused by buildings and structures. Results are based on analysis of the as-installed prototype network and a summary report completed by Alvarion (Internal report: BreezeMAX Extreme. Nortel Government Solutions, Radio Network Plan Report. Alvarion Technical Report, ITT/FAA, September 4, 2009).

The Radio Network Plan included the following simulations and procedures:

- The BS antenna sector pointing was analyzed.
- Azimuth pointing angles were determined manually.
- Antenna down-tilt angles were selected to provide the widest coverage area on the airport surface.
- Three-dimensional representations of buildings and structures were entered to add accuracy to the coverage predictions.
- Plots of signal strength and best sector grids were run after the sectors were arranged.
- Plots were run at 12- and 25-ft SS mounting heights to account for the varying mounting heights used in the test bed.
- A channel frequency plan was validated within the available 5091- to 5150-MHz AeroMACS spectrum allocation.

Figure 6 is an illustration of the NASA Glenn and CLE properties with building footprints that were included in the model highlighted.

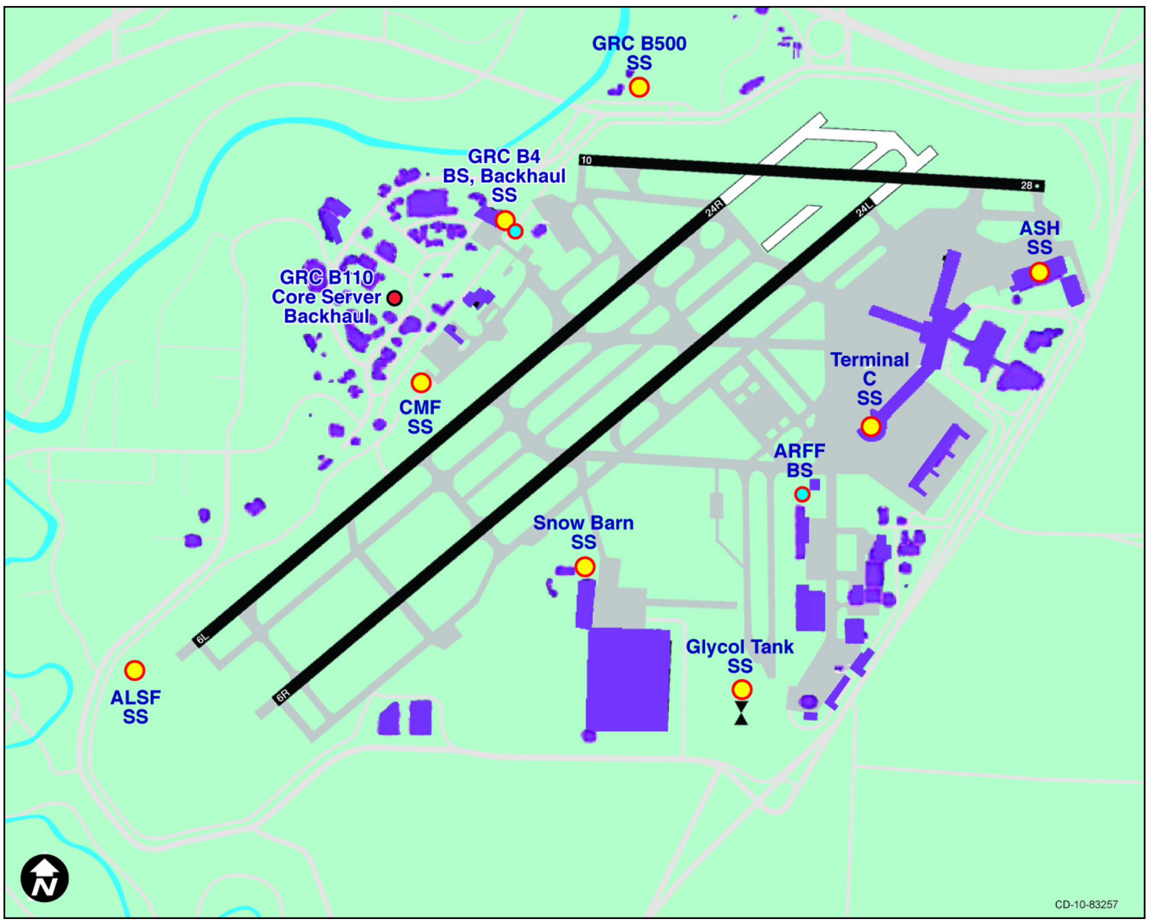


Figure 6.—Cleveland Hopkins International Airport with building footprints highlighted. Acronyms are defined in Appendix A.

The BTS sector and SS performance parameters summarized in Table 5 and Table 6 were used in this analysis. The channel assignments and antenna pointing angles are defined in Table 7. Center frequency assignments used for the BTS sectors in the analysis are defined in Table 8. The frequency assignments and BTS designators used in the test bed physical implementation were similar to those used in this analysis, except the frequencies were shifted to conform to the AeroMACS profile and BTS labels changed as installed.

TABLE 7.—BASE TRANSCEIVER STATION (BTS) SECTOR CONFIGURATIONS FOR ANALYSIS

Base station	Location	Building	Sector[a]	Channel	Azimuth, deg	Tilt, deg	Height, m
1	NASA Glenn	4	BTS1_1	F1	55	1	20
			BTS1_2	F5	200	1	20
2	CLE	ARFF[a]	BTS2_1	F2	45	1	10
			BTS2_2	F4	185	1	10
			BTS2_3	F3	295	1	10

[a]Aircraft Rescue and Firefighting building.

TABLE 8.—BASE STATION SECTOR CHANNEL-FREQUENCY ASSIGNMENTS FOR ANALYSIS

Channel	Frequency center, MHz
F1	5093.5
F2	5103.5
F3	5113.5
F4	5123.5
F5	5133.5

Figure 7 and Figure 8 are plots of DL (BS to SS direction) performance in the coverage area for 12-ft and 25-ft SS mounting heights, respectively. The eight fixed SS locations are indicated by yellow circles. Sensitivities are based on a fade margin of 10 dB. The color scale references the highest order of IEEE 802.16–2009 waveform modulation that can be supported for the signal level predicted to be present at each location.

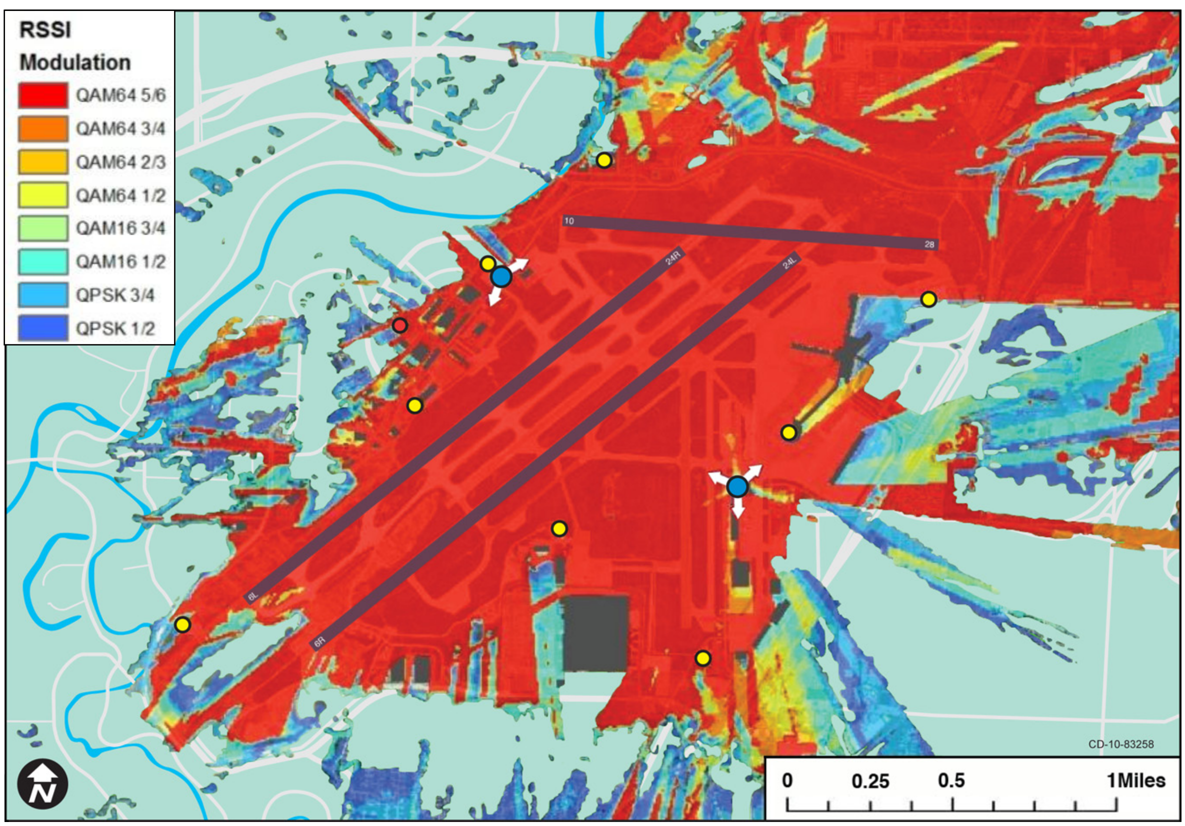


Figure 7.—Received signal strength indication (RSSI) plot for 17-dBi directional subscriber station mounted at 12 ft. Acronyms are defined in Appendix A.

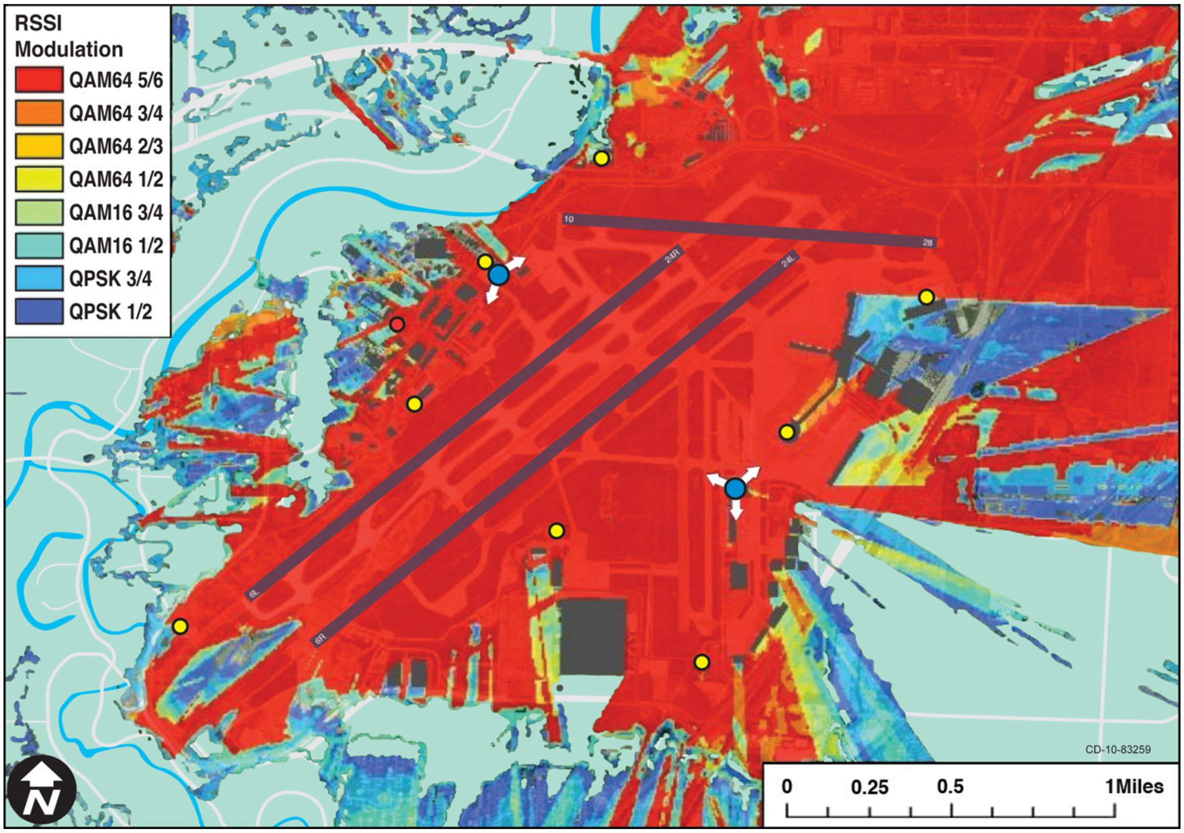


Figure 8.—Received signal strength indication (RSSI) plot for 17-dBi directional subscriber station mounted at 25 ft. Acronyms are defined in Appendix A.

As stated above, this analysis and results are based on a fade margin of 10 dB. This value is commonly applied to fade margin for fixed LOS microwave links. However, the value for fade margin assigned for analysis will affect the reliability of the link. The AeroMACS prototype can be used in the future to conduct link experiments to determine the correct value to apply for an operational AeroMACS network in the airport environment. Analyzing mobile links will require a different fade margin, which should also be validated with prototype tests.

A comparison of the plots in Figure 7 and Figure 8 reveals little difference in performance for the two SS mounting heights. 64–QAM with an FEC code rate of 5/6, which results in the highest data throughput rates, is achievable over the majority of the airport surface. Exceptions to the highest order modulation rate occur in areas where both BSs are shadowed from the SS by buildings. Varying levels of modulation are predicted in these regions, ranging from lower orders of QAM and FEC coding, down through QPSK, with small regions or the airport surface predicted to have no link support in this particular configuration. A region of shadowing is predicted to occur on the north side of the airport terminal buildings where LOS to both BSs is blocked by the buildings. During the design of an operational AeroMACS network, the system designer may choose to locate the airport-side BS(s) in position(s) that will provide more complete coverage in the terminal area; include an additional BS for terminal coverage, or in the future, make use of repeater stations as specified in the IEEE 802.16j amendment (Ref. 6) that has been incorporated into the IEEE 802.16–2009 standard.

A “best sector” plot is shown in Figure 9. This plot indicates which BTS sector is predicted to provide the best link sensitivity to a given SS. The calculations demonstrate that each sector supports at least one fixed SS. For comparison, Figure 10 illustrates the BTS sector that is closest to each SS location. Because of the shadowing effects of building structures, the closest sector to a SS location is not necessarily the optimal choice for link performance.

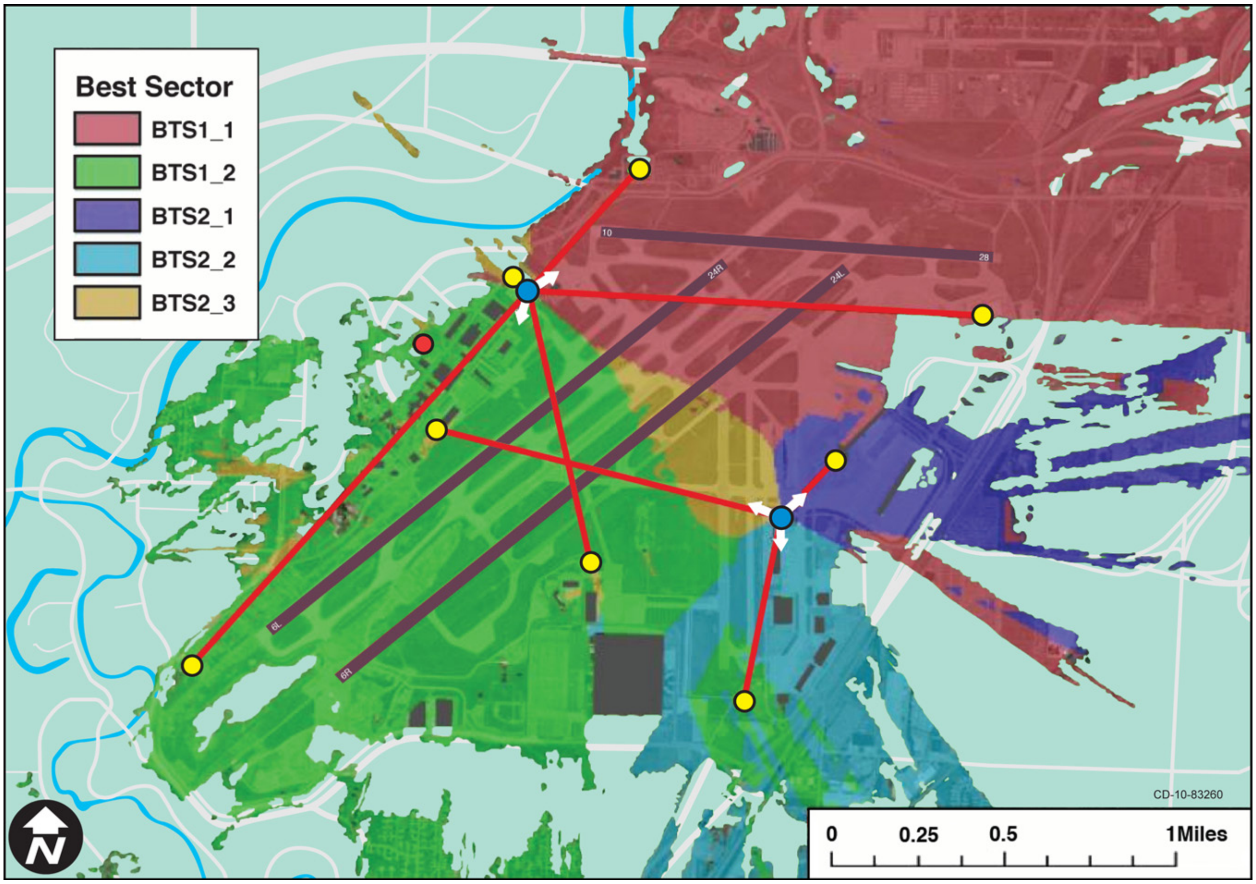


Figure 9.—Connection map for each subscriber station based on received signal strength indication (RSSI). Acronyms are defined in Appendix A.

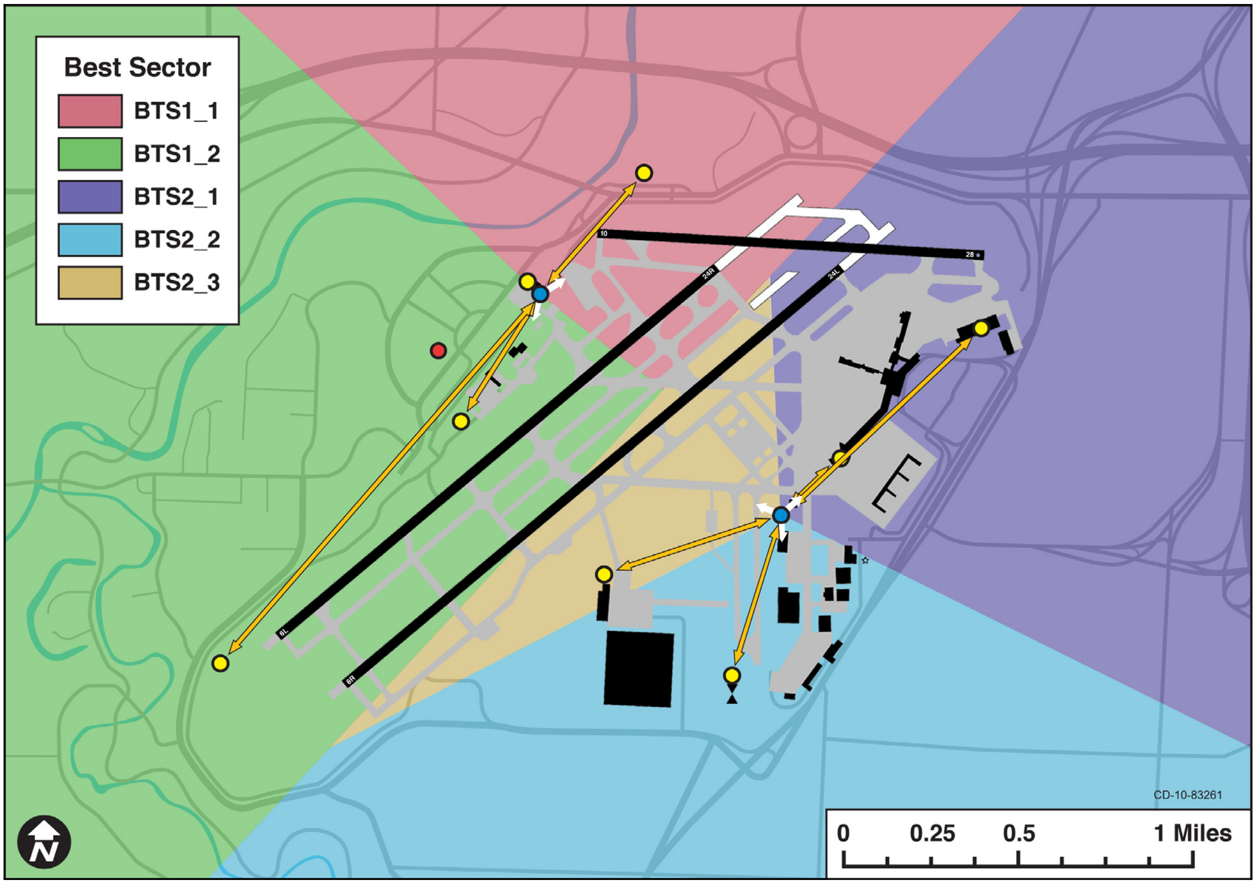


Figure 10.—Connection map for each subscriber station based on nearest base transceiver station (BTS) sector.

One SS location, the Aviation Services Hangar (ASH) on the CLE property, is on the edge of coverage from the BS at NASA Glenn's Building 4 and is shadowed from the BS at CLE's ARFF building. However, because the SS at this location is mounted 40 ft above the ground level, it provides a clear LOS view over the airport terminal building to the BS at NASA Glenn's Building 4.

2.3.2 Network Test and Evaluation Results

For the AeroMACS prototype network, two BS locations were added to the NASA–CLE CNS Test Bed on opposite sides of the airport runways to provide wide coverage over the airport surface. Network operational redundancy results because each SS typically has one or more sectors from both BSs within view and is thus able to connect to either BS. An interruption of the established link between a BS and a fixed SS, caused by blockages or obstructions, will cause the SS to use its mobility handoff capability to rapidly reestablish its data flow through the other BS. This capability may not be required, depending on the reliability requirements of applications, but it is available in the AeroMACS prototype for testing purposes.

For several practical reasons, SS locations were selected to match the sensor sites of the original Sensis Corporation MLAT surveillance sensor sites in the NASA–CLE CNS Test Bed. The transition of operational MLAT surveillance sensor wireless connections to AeroMACS is a potential fixed AM(R)S service application. For this reason, the NASA–CLE CNS Test Bed is an ideal location for an AeroMACS prototype. These existing sites provide IP data streams from already installed MLAT data sensors, provide simplified installation on existing mounting structures, and have electrical power sources already available to power the SSs. In addition to the sensor data sources, a SBC is co-located at each SS site to provide known data streams for evaluating AeroMACS link performance.

All AeroMACS prototype network hardware planned for the initial phase of AeroMACS testing has been installed at NASA Glenn and CLE as described in the following list. Locations can be referenced on the airport layout diagrams (Figure 1 and Figure 2).

NASA Glenn Installation Sites

- Building 500 roof
- SS unit
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies
- Building 4 roof
- SS unit
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies
- 11-GHz wideband microwave backhaul link outdoor unit to connect this BS to the core server in Building 110
- 80-ft radio tower adjacent to Building 4
- BS with two BTS sectors mounted at 60 ft above the ground level
- Two global positioning system (GPS) outdoor units mounted at 66 ft above the ground level to support the BTS outdoor units
- Building 4 indoor room
- Equipment rack with BTS power supplies, managed Ethernet switch, and microwave backhaul link indoor unit and power supply
- Building 110, Room 310
- Equipment rack with the following CSN and data backhaul functions
- Secure network router
- Authentication, authorization, and accounting (AAA) server
- Network Management System (NMS) server
- Data backhaul indoor units for links to Building 4 and ARFF building BSs
- Power supplies for servers and backhaul radios
- SBC connected to the secure router

Cleveland Hopkins Airport Installation Sites

- ARFF building roof
- BS with three BTS sectors mounted on a nonpenetrating roof-mount antenna mast
- Three GPS outdoor units mounted on antenna mast above BTS outdoor units
- 11-GHz wideband microwave backhaul link outdoor unit to connect this BS to the core server in Building 110 mounted on the antenna mast
- ARFF building indoor room
- Equipment rack with BTS power supplies, managed Ethernet switch, microwave backhaul link indoor unit and power supply
- Aviation Services Hangar roof
- SS mounted to rooftop support beams
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies mounted to rooftop support beams
- Terminal C roof
- SS mounted to Sensis equipment rack
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies mounted to Sensis equipment rack
- Glycol Tank support building
- SS mounted on external-wall-facing runways
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies mounted on external-wall-facing glycol tanks

- Snow Barn building
- SS mounted near roof line
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies mounted inside of the building
- Approach lighting with sequenced flashing lights (ALSF) tower near ALSF building
- SS mounted on tower section
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies mounted on short tower
- Consolidated Maintenance Facility
- SS mounted on roof edge near Sensis antennas
- Support electronics enclosure for SS with a managed Ethernet switch, SBC, and power supplies mounted inside of building

Figure 11 to Figure 19 are photographs of AeroMACS hardware installations with key components highlighted. Figure 11 shows the BS1 and data backhaul radio outdoor unit at NASA Glenn's Building 4 (hangar). Two BTS outdoor units (ODUs) with built-in sector-coverage antennas are mounted 60 ft above the ground level on the radio tower that already existed beside Building 4. A separate GPS ODU is mounted to the tower 6 ft above each BTS outdoor unit. GPS signals are used by the BTS ODUs for precise timing and coordination of their transmit/receive operation.

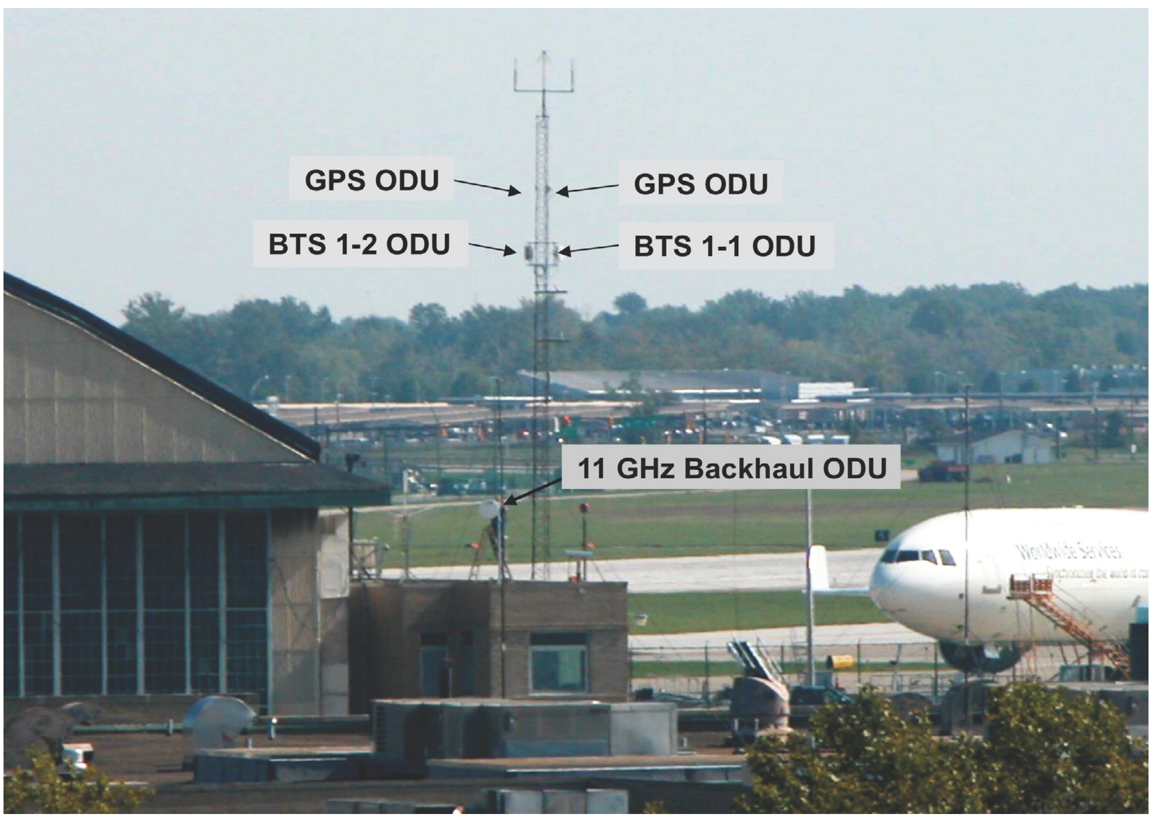


Figure 11.—Base transceiver station (BTS) sectors, Global Positioning System (GPS) receivers, and data backhaul installation at NASA Glenn Building 4.

Figure 12 shows the BTS and data backhaul equipment rack that is located in an indoor room within Building 4. The Lambda 48-Vdc supply powers the 11-GHz data backhaul indoor unit (IDU) and ODU. Two 55-Vdc power supplies running on 220 Vac are inside the rack that powers the BTS sector radios through a power-over-Ethernet (PoE) cable that also carries BS data traffic.

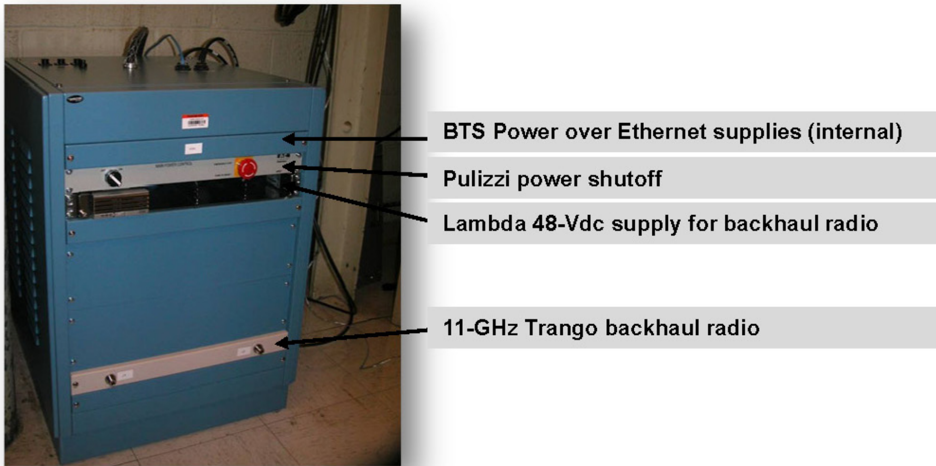


Figure 12.—Base transceiver station (BTS) and data backhaul equipment rack inside NASA Glenn's Building 4

Figure 13 shows an SS on the roof of NASA Glenn's Building 500. The SS radio and the SS electronics enclosure are mounted to the MLAT surveillance equipment rack that was installed by Sensis Corporation during the original development of the NASA–CLE CNS Test Bed. SS installations at NASA Glenn's Building 4 and at CLE's Concourse C are similar; the SS hardware is mounted to an existing Sensis equipment rack. The other five SS installations use varying methods of mounting SS equipment to existing structures.

Figure 13.—Subscriber station and enclosure at NASA Glenn's Building 500. Acronyms are defined in Appendix A.

In Figure 13 the SS ODU is pointed toward the BS1 near NASA Glenn's Building 4. The electronics enclosure is mounted on the opposite end of the equipment rack. The remaining enclosures are from the original MLAT surveillance installation and are only related to the AeroMACS network as sources of live data for potential service demonstrations.

Figure 14 shows the internal components of a representative electronics enclosure associated with each SS in the prototype network taken during the installation phase. Therefore, not all internal cabling is shown in this photograph. Identical electronics enclosures are installed at all SS installation sites.

Figure 14.—Internal electronics of subscriber station (SS) enclosure.

The SS power supply in the lower right-hand corner of the enclosure runs on 110 Vac and provides 48 Vdc as PoE. Above the SS power supply is an Ethernet input/output board with a SBC beneath it. The SBC uses a Linux operating system and hosts Chariot test software from Ixia. Chariot can be controlled through the network to generate and receive test data streams that are used to evaluate AeroMACS link performance. A lightning arrestor for PoE lines to the SS is shown in the upper left-hand corner.

The managed Ethernet switch in the upper left-hand corner provides connections for the SS, the SBC, and up to two other devices that have an IP-based Ethernet interface. Connection is with a standard RJ–45 connector. This is the interface that was used to connect the MLAT surveillance sensors into the AeroMACS prototype in an experimental test.

The enclosure includes provisions for environmental control to protect the internal components. A fan is visible in Figure 14 that is on a temperature sensor and draws outside air into the enclosure above a set temperature. In addition, heating elements that are activated at a set temperature are mounted behind the aluminum mounting plate.

Figure 15 shows the 11-GHz data backhaul radio ODU located on the roof of NASA Glenn's Building 4 during installation. This radio provides the data link with a similar radio on the roof of NASA Glenn Building 110. Figure 16 shows the NASA Glenn Building 110 end of this link and a second backhaul radio that supports the link to the BS located about 1 mile across the airport surface at CLE's ARFF building.

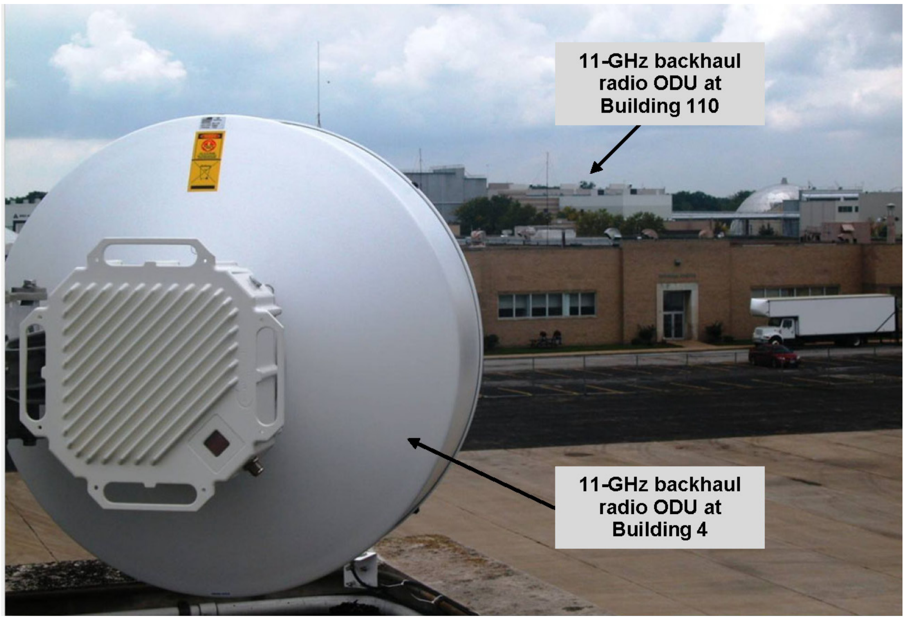


Figure 15.—11-GHz backhaul radio outdoor units (ODUs) at NASA Glenn's Building 4 and Building 110.

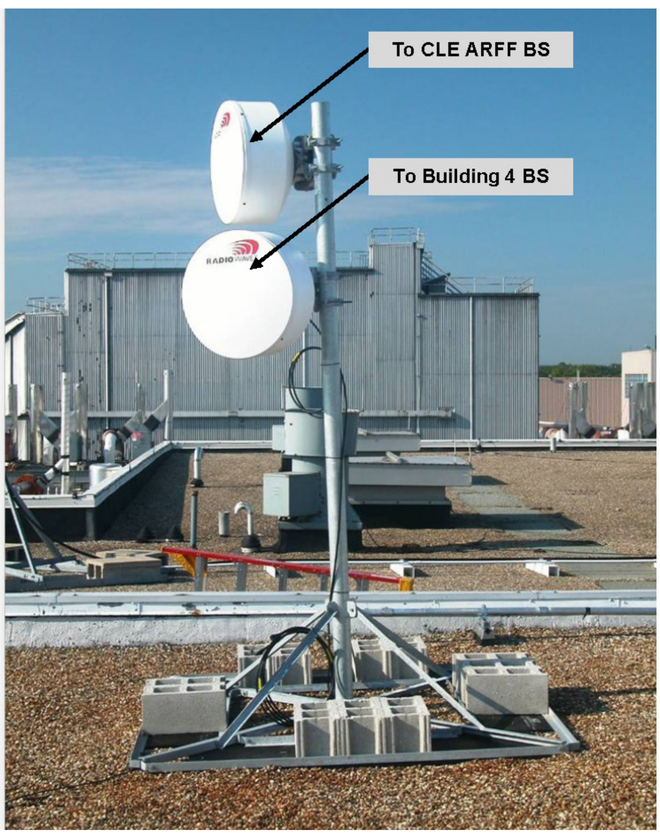


Figure 16.—11-GHz backhaul radio outdoor unites (ODUs) at NASA Glenn Building 110 with links to NASA Glenn Building 4 base station (BS) and to Cleveland Hopkins International Airport's (CLE) Airport Rescue and Firefighting (ARFF) building.

The airport-side BS2 is located on the roof of the ARFF building observation deck as shown in Figure 17with a close-up view of the antenna mast and mounted components shown in Figure 18. The close-up view clearly shows the nonpenetrating roof-mount antenna mast that supports AeroMACS outdoor unit components and the 11-GHz backhaul radio that is pointed toward NASA Glenn Building 110.

Figure 17.—Aircraft Rescue and Firefighting (ARFF) building base station on observation deck roof.

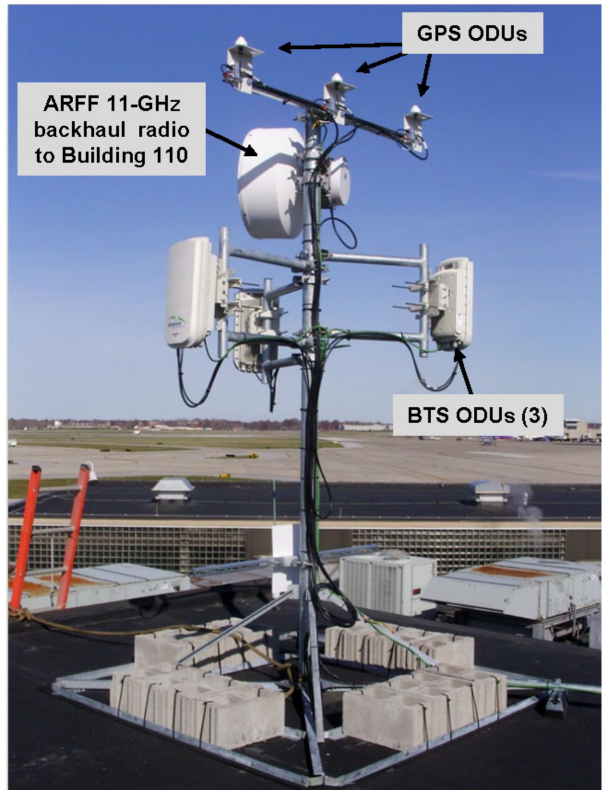


Figure 18.—Detailed view of base station at Aircraft Rescue and Firefighting (ARFF) building. Acronyms are defined in Appendix A.

Three IEEE-802.16–2009-compliant AeroMACS BTS radios are mounted to the mast: each on a standoff arm. The separation of the standoff arms increases RF isolation between units and decreases the potential for in-band interference. The 11-GHz backhaul radio with its 2-ft-diameter dish antenna is mounted on the mast above the AeroMACS radios. Three GPS outdoor units are mounted on a bar above the backhaul radio at the top of the antenna mast. The GPS outdoor units support the three AeroMACS radios for precise timing, with one GPS outdoor unit connected per radio.

The equipment shown in Figure 19 comprises the AeroMACS prototype network core where data are aggregated from BSs and SSs and then disseminated to various data users. The equipment is a combination of power management breakers and switches, IDUs for the two data backhaul radios and their power supplies, computer servers to host the CSN functional software, and a secure Ethernet router.

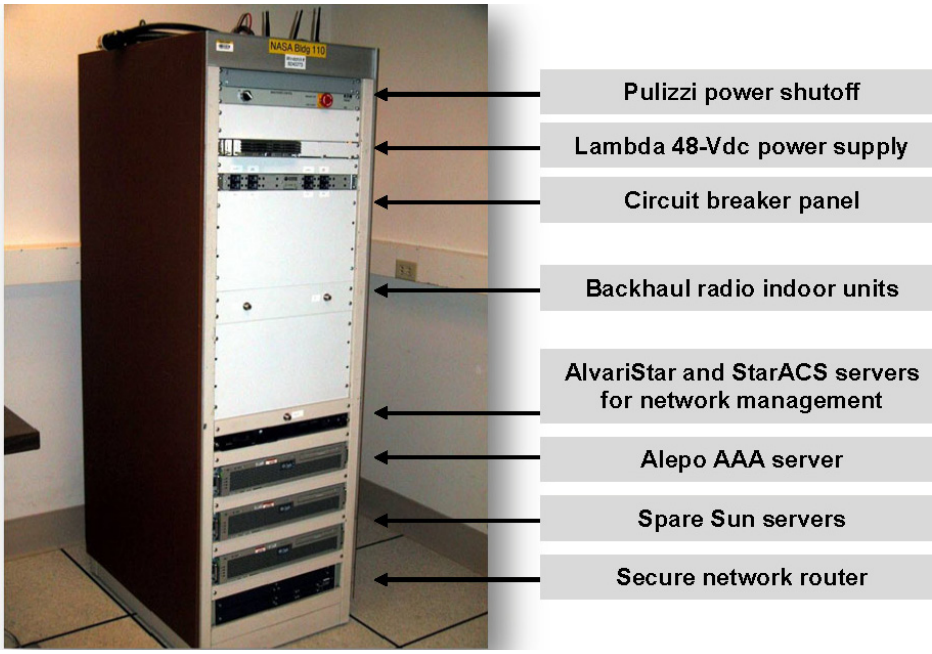


Figure 19.—AeroMACS network core equipment in NASA Glenn's Building 110, Room 310. Acronyms are defined in Appendix A.

The network architecture illustrated in Figure 20 can be used to understand the functions of the servers and secure router in the core network. The AeroMACS prototype network core equipment rack (shown in Figure 19) includes one server more than is needed to host the CSN functions because one server was found to be able to host both the NMS and the AAA functions. The major CSN functions and their corresponding programs are described in the following paragraphs.

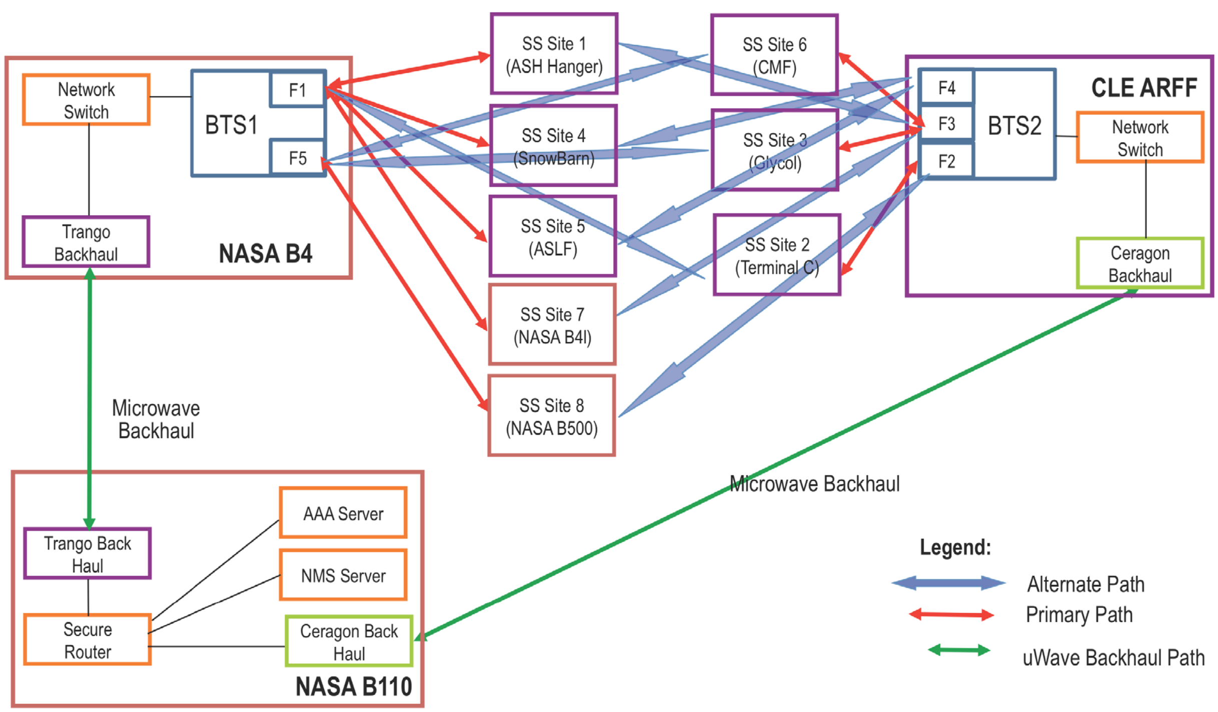


Figure 20.—802.16–2009 AeroMACS prototype core network diagram. Acronyms are defined in Appendix A.

AlvariStar, developed by Alvarion[6], is a telecommunications-class NMS provider used for managing commercial mobile WiMAX BSs that supports the operation of the prototype AeroMACS network BSs without modification. The AlvariStar NMS supports common network management applications in compliance with telecom industry standards, providing comprehensive fault, configuration, performance and security management functionality. It provides network surveillance, maintenance, and fault-handling capabilities. The AlvariStar NMS is designed to support a variety of system architectures ranging from a single-airport size of network, where AlvariStar resides on a single computer server, to a fully distributed system that would support multiple airports.

A server running Alepo software, by Alvarion, AAA functions for commercial mobile WiMAX networks and can be used to operate an AeroMACS network without modification. When an SS requests entry into the AeroMACS network, the Alepo AAA server refers to a preprogrammed data base, validates the SS identity, and authorizes or rejects entry into the network. For SSs that are allowed entry, the AAA server determines from its data base the level of QoS that the network should provide. Alepo's AAA server is fully compliant with the IEEE 802.16–2009 and WiMAX Forum Network Working Group standards.

The Star Automatic Configuration Server (StarACS), by Alvarion, provides a unified and standardized system for managing a variety of SSs. Developed for the commercial WiMAX industry, the StarACS can support AeroMACS SSs without modification. It provides mass configuration updates, software upgrades, maintenance, and troubleshooting of SSs through the network, and provides integrated operation with Alvaristar and other higher-level NMSs.

Figure 20 identifies the interconnections between components of the AeroMACS prototype network that was added to the NASA–CLE CNS Test Bed. At the center of the network is the secure router that enables secure virtual local area network (VLAN) data paths to be established through virtual private network (VPN) routes. With this capability, VLAN data channels can be established end-to-end through the AeroMACS network from an SS to an Ethernet port on the secure router that is kept private and secure from all other VLAN channels.

A data path between the SSs and a port on the secure router is established on a VLAN in order to connect the AeroMACS network to the laptop personal computer (PC) that hosts Ixia Chariot test software and controls network tests. Additional user IP ports at the secure router can be established for datapath connections through the AeroMACS network. Traffic from the Sensis Corporation MLAT sensor sites was carried on the data plane VLAN to a data port on the secure router. MLAT system sensor data was then made available for MLAT processing with the data transported to the processors over an Ethernet connection.

In addition to the data plane, a control plane is established on a separate VLAN through the secure router. In this manner, control traffic from the AlvariStar, Alepo AAA, and StarACS applications is segregated through the network on VLAN. In addition, an Internet connection is isolated from the rest of the AeroMACS network though the use of a VLAN channel to the PC.

[6] Alvarion Ltd., http://www.alvarion.com/index.php/en-US/support/international-customer-support

3.0 AeroMACS Prototype Network Evaluation

This report presents two sets of network test results based on tests conducted at the AeroMACS prototype network in the NASA–CLE CNS Test Bed. The first set, completed in early 2010 in Task 7-1 Phase I, collected baseline network performance soon after AeroMACS capabilities were added to the Test Bed. These tests and associated test results are described in Section 3.1. The second set of test plans and corresponding results are reported in Section 3.2 for work completed under Phase II of contract Task 7-1. The Phase II tests were designed to help refine AeroMACS network profile requirements and to demonstrate AeroMACS utility in handling applications.

3.1 Baseline Performance Tests

Eleven network tests were defined to establish the IEEE–802.16–2009-based operating capability added to the NASA–CLE CNS Test Bed. The tests established operating capabilities in the following areas of network operation.

- Security with authentication and encryption
- Data throughput and channelization
- QoS data prioritization
- Mobility at motor vehicle speeds
- Reliability during extended operation

3.1.1 Phase I Test Cases

The eleven baseline test cases and their intended objectives follow.

Test case 1—Network entry with authentication and data transfer

The purpose of this test was to verify that a service flow is successfully created when an SS enters the network and that the service flow is removed completely when the SS exits the network. This test case also verified that a valid user ID and/or password are required to successfully enter the network. Furthermore, this test case verified that a bidirectional path (UL/DL) is successfully set up after network entry.

Test case 2—QPSK throughput, UL and DL

This test case verified the baseline maximum throughput from LOS within the sector using QPSK rate 1/2 coded modulation. For this test case, LOS also included near or partial LOS.

Test case 3—16-QAM throughput, UL and DL

This test case verified the baseline maximum throughput from LOS within the sector using 16–QAM rate 1/2 coded modulation. For this test case, LOS also included near or partial LOS.

Test case 4—64-QAM throughput, DL

The purpose of this test was to verify the baseline maximum throughput from LOS within the sector using 64–QAM rate 1/2 coded modulation on DL. For this test case, LOS also included near or partial LOS.

Test case 5—Sector capacity with multiple SSs

This test demonstrated the operation of multiple SSs within a sector to test the maximum throughput capacity of a single sector and the capability of a sector to handle terminal network entries in congested conditions.

Test case 6—Multiple BTS throughput

This test demonstrated the operation of multiple SSs across multiple sectors to test the maximum throughput capacity of multiple BTSs and the capability of multiple sectors to handle terminal "network entries" in congested conditions.

Test case 7—QoS—DL non-real-time (nRT) prioritization over best effort with two terminals

This was a data prioritization test to verify the handling of data on the DL classified as high priority. It verified that an nRT protocol data stream is prioritized over a best-effort data stream when both data types are sent to the same SS.

Test case 8—QoS—UL nRT prioritization over best effort with two terminals

This was a data prioritization test to verify the handling of data on the UL classified as high priority. It verified that an nRT protocol data stream is prioritized over a best-effort data stream when both data types that are sent originate from the same SS.

Test case 9—Intrasector mobility with link adaptation

This tested the ability to maintain a user datagram protocol (UDP) traffic stream while mobile in a single BTS sector with link adaptation enabled. This test demonstrated the network's ability to switch between QPSK, 16–QAM, and 64–QAM using adaptive modulation and coding.

Test case 10—Intersector mobility with link adaptation

This test evaluated BTS handover ability for a mobile SS that moves over multiple sectors and the ability to maintain a UDP traffic stream while moving about multiple sectors with link adaptation enabled. This test demonstrated the network's ability to switch between QPSK, 16–QAM, and 64–QAM using adaptive modulation and coding.

Test case 11—Long-term stability test

This was an extended-operation test to verify network stability by periodically sending and receiving data bursts.

3.1.2 Phase I Test Status and Results

The operational integrity of the AeroMACS prototype was verified with the eleven baseline tests based on existing hardware capabilities. The tests that involved mobility (Test cases 9 and 10) were not completed because the hardware available during Phase I could not support mobility hand-over. Results from the remaining tests provided a deeper understanding of AeroMACS capabilities and were used to guide development of the Phase II test plan.

The AeroMACS radio link between the SS on the roof of NASA Glenn Building 500 and the two BTS sectors at NASA Glenn Building 4 was evaluated during Phase I testing. The link to BTS1-1 sector is LOS with a distance of approximately 775 m. The SS is within the main lobe of the BTS1-1 sector antenna. For the second link, the SS is behind the BTS1-2 sector ODU and in its antenna side lobes. However, the signal strength for the second link was still adequate to support the highest modulation level of the 64–QAM, 5/6 code rate.

Iperf network performance software was used in these tests to simulate traffic across the radio link. Iperf is an open-source application that generates transmission control protocol (TCP) and UDP packets to measure network performance.

The following parameters were set for the link tests:

- Service type, Ethernet Layer 2
- QoS type, best effort
- Connection time, short
- Committed information rate, 7 Mbps

Test conditions

- Channel bandwidth, 5 MHz
- Received signal strength indication (RSSI), >−70 dBm
- Signal-to-noise ratio, >24 dB
- Modulation, 64−QAM 5/6
- MIMO, 2×2 at BTS sectors, 2×1 at SS
- Test computer hosting Iperf connected to the data interface on the BTS
- Test computer hosting Iperf connected to the SS Ethernet port
- TDD ratio: 60 percent (DL); 40 percent (UL)

Procedures

- Run the Iperf performance software server on the computer at the BTS.
- On the computer connected to the SS, execute a throughput test using the parameters in Table 9.
- TCP test—This test will simulate upstream and downstream traffic using the File Transfer Protocol (FTP).
- Server-side, Iperf –s –w64k –il
- Client-side, Iperf –c [Server IP Address] –t60 –w64K –i1 –P2

All the parameters listed in Table 9 affect the net data throughput that can be achieved (Ref. 7).

TABLE 9.—AeroMACS PARAMETER SETTINGS AFFECTING THROUGHPUT

BW	Nominal channel bandwidth, 5, 10, or 20 MHz
N_{used}	Number of subcarriers used (data and pilot subcarriers)
N_{data}	Number of data subcarriers
n	(Over-) Sampling factor, 8/7 or 28/25
G	Ratio of cyclic prefix (CP) time to useful time (default $G = 1/8$)
N_{FFT}	Fast Fourier transform size: smallest power of 2 greater than N_{used} (512 or 1024)
F_s	Sampling frequency, F_x = floor ($n \times BW/8000$) × 8000
Δf	Subcarrier spacing, $\Delta f = F_s/N_{\text{FFT}}$
T_b	OFDM symbol time, $T_b = 1/\Delta f$
T_g	Cyclic prefix (CP) time, $T_g = G \times T_b$
T_s	CP–OFDM symbol time transmitter, $(Tx) = T_b + T_g = (1 + G) \times T_b$
M	QAM modulation order, 2(QPSK), 4(16−QAM), or 6(64−QAM)
r_{FEC}	FEC coding rate, 1/2, 2/3, 3/4, or 5/6
r_{Rep}	Repetition code rate, 0, 2, 4, or 6

The expected throughput performance under the conditions listed in Table 10 and under other settable parameters is estimated by the equipment manufacturer to be 6.5 Mbps in the DL direction from BS to SS and to be 4.0 Mbps in the UL direction from SS to BS. The expected values and actual throughput test results are compared in Table 10. The measured throughput exceeded the manufacturer's estimated rates in all cases.

TABLE 10.—AeroMACS NASA–CLE TEST BED LINK TEST RESULTS
[Acronyms are defined in Appendix A.]

BTS sector	Measured DL throughput, Mbps	Expected DL throughput, Mbps	Measured UL throughput, Mbps	Expected UL throughput, Mbps
BTS1_1	6.82	6.5	5.4	4.0
BTS1_2	6.54	6.5	4.19	4.0

3.2 Phase II Test Case Description and Test Results Analysis

A test plan was established for Task 7-1 Phase II that governed testing in areas that are important for establishment of an AeroMACS network profile. The test plan is included in Appendix B of this report. The following four tests were included:

- Test Case 1, MLAT Communications
- Test Case 2, AeroMACS Mobility Test
- Test Case 3, Channelization Tests
- Test Case 4, Transmit Power Requirements

3.2.1 Test Case 1, MLAT Communications

3.2.1.1 Test Objectives

A series of tests measured the network performance of the AeroMACS prototype network for communication of MLAT surveillance sensor data traffic. End-to-end network performance was evaluated using live connections to MLAT sensor stations in the NASA–CLE CNS Test Bed plus test data streams generated by IxChariot software. Use of IxChariot allowed realistic MLAT-like traffic to be generated and carried through the AeroMACS network concurrent with live MLAT data. The IxChariot data streams allowed network performance statistics to be collected. Live MLAT data was from eight MLAT sensor sites in the test bed.

3.2.1.2 Test Method

The NASA–CLE CNS Test Bed was originally constructed with eight MLAT sensor sites located at the Cleveland Hopkins airport and on the adjacent NASA Glenn property. The eight MLAT sensors receive aircraft transponder transmissions and send processed information to a sensor fusion data processing unit called the Target Processor that computes most likely aircraft transponder locations and displays the locations graphically.

MLAT evaluation tests involved first making the connection for MLAT traffic transfer from the MLAT sensor, built and installed by Sensis Corporation, to the AeroMACS SS. The AeroMACS SS equipment installed by ITT includes a network managed switch on the IP port of each SS. This five-port network switch is used to interface traffic from the MLAT sensor, the SBC running IxChariot test software, and other IP applications with the SS IP port. The network ports on the managed network switch are controllable through the network in order to enable/disable traffic from one or more applications.

The physical interface between MLAT sensors and the AeroMACS network switches is a short Ethernet cable. Each MLAT sensor issues live raw MLAT data as multicast IP traffic. A burst of 278 bytes is multicast in UDP format for each transponder transmission received. When emulated MLAT

traffic is added for network evaluation, traffic is generated using IxChariot software in UDP frame bursts of 278 bytes at a rate of 22 frames per second, generating a test traffic flow of 50 kbps.

3.2.1.3 Test Results

The initial evaluation of AeroMACS' ability to support the MLAT surveillance application was to enable data flows from each of the eight MLAT sensor sites. Live MLAT data then flowed from the sensor, through the AeroMACS SS to BS air links, through the microwave backhaul links, and to the secure router located in NASA B110. MLAT traffic was carried through the AeroMACS network on the data plane VLAN to a secure port on the router in B110. MLAT traffic was transported via Ethernet from the secure router to the Sensis MLAT Target Processor also located in B110. Real-time aircraft transponder location information was then displayed graphically by Sensis, showing positions on a map of the Cleveland Hopkins airport as shown in Figure 21.

Live MLAT traffic was carried over the AeroMACS network to support a near real-time display of aircraft activity at CLE airport during a tour of the NASA–CLE CNS Test Bed and the AeroMACS prototype in August 2010, for attendees of the RTCA SC–223 Plenary meeting. The following traffic was carried simultaneously through the AeroMACS prototype network for this demonstration:

1. MLAT traffic from eight sensor sites via the AeroMACS prototype network to the Sensis Target Processor for aircraft transponder position display
2. Live compressed video link bidirectional between B110 to the mobile ARV
3. Live compressed video link from two NASA building rooftop installations to B110
4. An example airline application provided by Continental Airlines originating from their Operations Center at CLE

Figure 21.—Multilateration (MLAT) display (center) during AeroMACS communications support.

The display of live MLAT targets with traffic carried over the AeroMACS prototype network was a nonquantitative and subjective evaluation. MLAT detected targets were displayed and the targets moved on the airport surface as expected. However, anomalous behavior was observed with targets briefly

disappearing from view and target positions were offset from what would be expected. The nonquantitative analysis did not separate possible degradation of MLAT system performance by the AeroMACS prototype network from the performance of the installed MLAT surveillance system, which had received limited maintenance at the time of this test.

A quantitative assessment of AeroMACS network support of MLAT traffic was completed by using IxChariot to generate MLAT-like traffic flows. IxChariot was used to collect statistics of traffic flow, sometimes with live MLAT traffic flowing through the network simultaneously. No impact was observed in the IxChariot performance statistics when live MLAT traffic feeds were active.

IxChariot traffic was generated at three SS sites for the emulated MLAT application evaluation: the CMF, Glycol Tanks, and NASA Building 4 sites. The three SS sites were linked into the AeroMACS network through BTS2-3 sector of BS2 as illustrated in Figure 22.

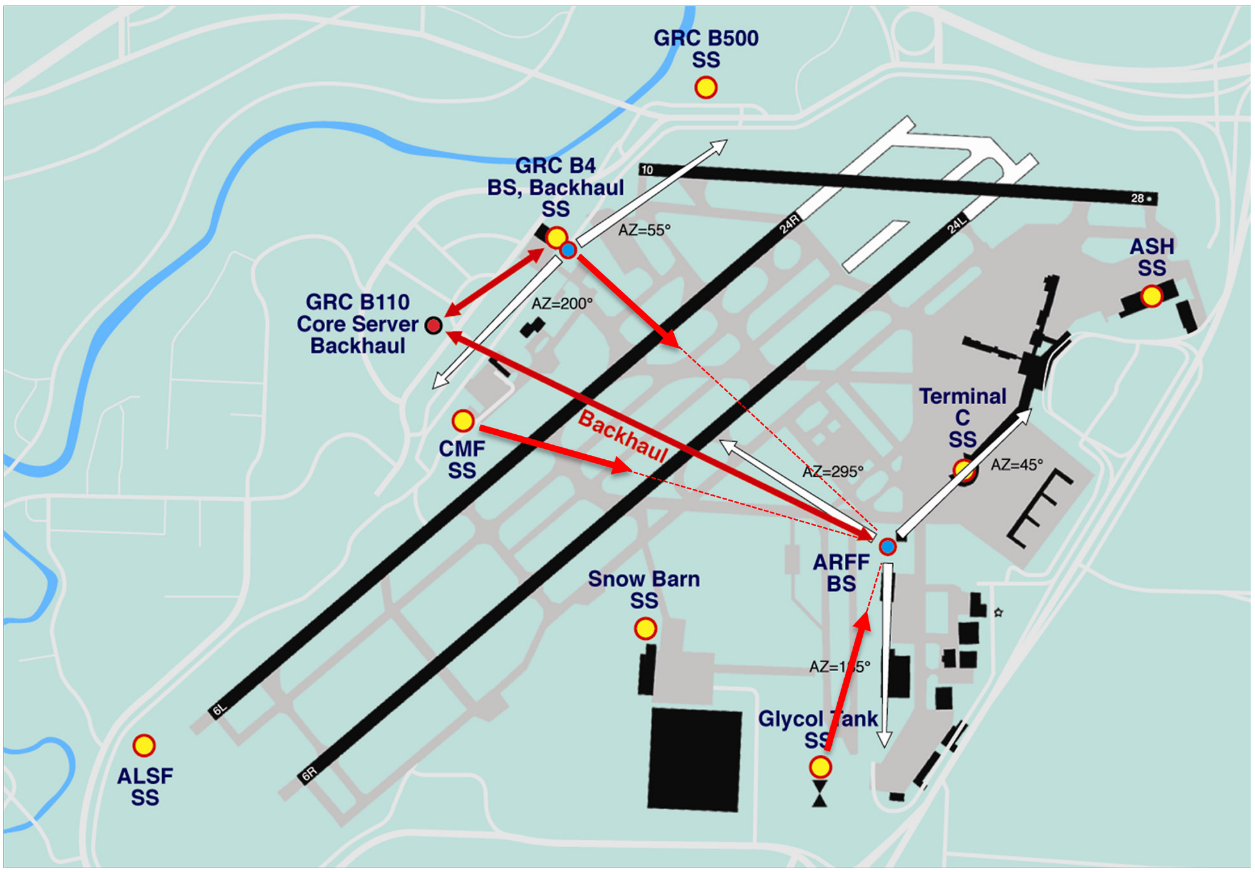


Figure 22.—Connectivity for multilateration evaluation.

AeroMACS prototype network support of MLAT surveillance application was first tested with the traffic flows listed in Table 11.

TABLE 11.—MULTILATERATION TEST DATA SOURCES

Location of SS	Traffic type	Traffic rate	QoS
NASA B4	288-byte bursts of random data	10- to 60-s intervals between bursts	non-real-time polling service (nrtPS) (high QoS)
Consolidated Maintenance Facility building	Packets with random payload	1.4 Mbps	best effort (BE) (lowest QoS)
Glycol tanks	Packets with random payload	1.4 Mbps	BE (lowest QoS)

Traffic throughput rate for the three test feeds listed in Table 11 are shown in Figure 23. MLAT-like traffic is shown at the lower edge of the plot as low rate bursts of traffic at 10 to 60 second intervals. This low-rate MLAT traffic plus the two 1.4-Mbps streams assigned best effort (BE) slightly exceeded the throughput capacity of BTS2-3 that they were all linked through, resulting in a packet error rate of approximately 0.5 percent for one of the BE traffic streams. No packet errors appear in the low-rate MLAT-like traffic that is assigned higher-priority non-real-time polling service (nrtPS) QoS service.

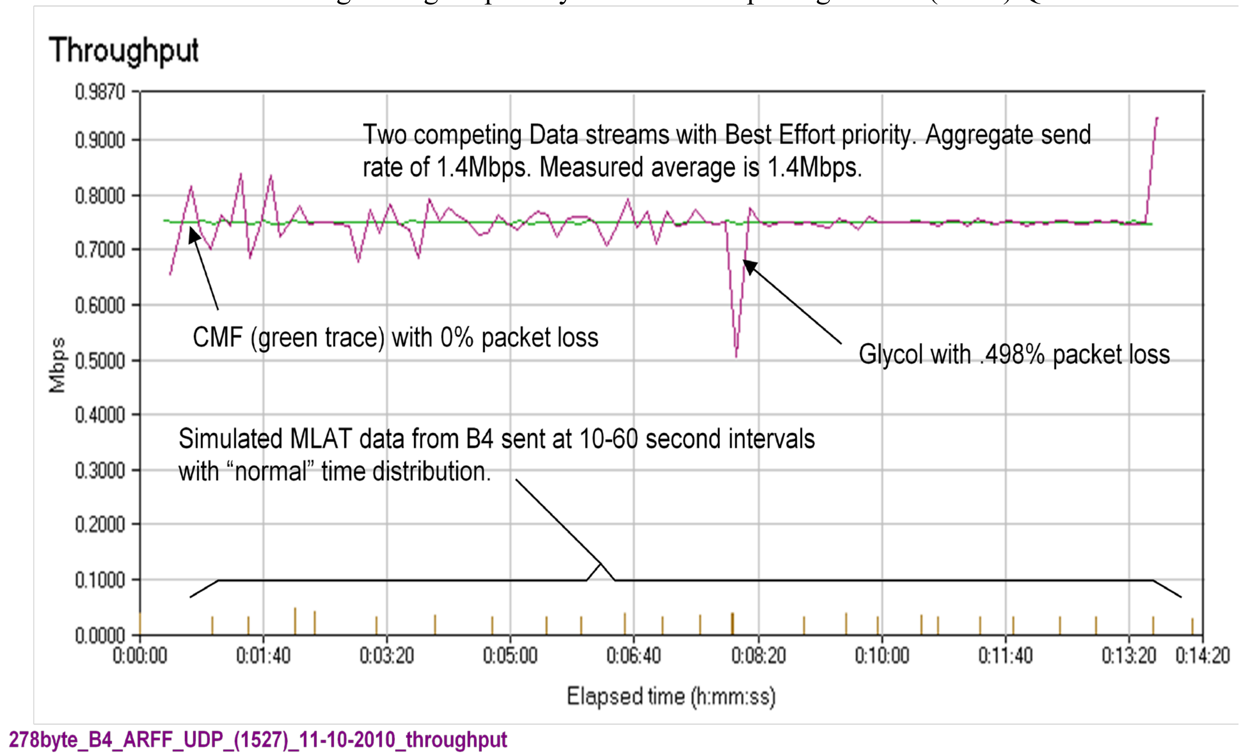


Figure 23.—Multilateration (MLAT)-like traffic from B4 SS plus background traffic.

IxChariot posttest analysis provided time latency information for the MLAT-like traffic. Figure 23 shows AeroMACS network response time for bursts of traffic originating at the NASA B4 SS. Traffic latency statistics for this test were

- Average = 67 ms
- Minimum = 47 ms
- Maximum = 73 ms

Tests were repeated with only one BE traffic stream plus the MLAT-like traffic bursts linked through BTS2-3 sector. Because that sector was not overloaded with traffic in this case, no packet errors were observed from the higher-rate BE traffic or the higher-priority MLAT-like traffic set to nrtPS QoS. Packet latency was nearly identical for the higher priority MLAT-like traffic whether or not the serving BS sector was overloaded with lower-priority BE traffic.

3.2.1.4 MLAT Surveillance Communications Observations

This evaluation of MLAT system support by an AeroMACS network included non-quantitative analysis with live MLAT traffic processed for graphical displays of aircraft positions, and quantitative assessments using software generated traffic of the packet size and rate used for MLAT but with no live

recorded or emulated MLAT information in the data packets. AeroMACS network support for MLAT should be further evaluated in the future to provide a complete assessment of potential performance impact.

3.2.2 Test Case 2, AeroMACS Mobility Test

3.2.2.1 Test Objectives

A series of tests evaluated the ability of a mobile AeroMACS SS to support communications under a variety of conditions:

- Mobile at speeds of at least 40 kt
- Single antenna and antenna diversity modes including single-input, single-output (SISO) and MIMO modes
- Omni antenna spacing of 2 to 10 wavelengths for dual-antenna MIMO diversity mode
- 5- and 10-MHz channel bandwidths
- Mobility across BS sector and BS regions requiring service handover

3.2.2.2 Test Method

Vehicles that may use an AeroMACS network for communications vary from slow service vehicles that mostly operate in terminal areas to aircraft that ideally will enter the network at high-speed shortly after landing. The mobile environment for an arriving aircraft will transition from the mostly open, low-multipath conditions of the movement area to the terminal and gate area where multipath will increase but ground speeds are lower. The propagation environment will transition back to high speeds in mostly open areas as the aircraft departs the terminal gate and taxis for takeoff.

The NASA AeroMACS Research Vehicle (ARV), shown in Figure 24, was used to test a mobile AeroMACS SS under the various conditions expected for the airport surface environment. An aluminum plate was mounted on the roof of the ARV as a ground plane for the AeroMACS antennas as shown in Figure 25.

The antennas used in the mobility tests are model SWA2459/360/20/V_2 from Huber-Suhner. These antennas exhibit constant gain of +8 dBi in ground plane directions. The gain pattern peaks toward the horizon because of the antenna orientation on the ARV.

Figure 24.—NASA AeroMACS Research Vehicle (ARV) being escorted by Federal Aviation Administration for mobility tests on CLE airport surface.

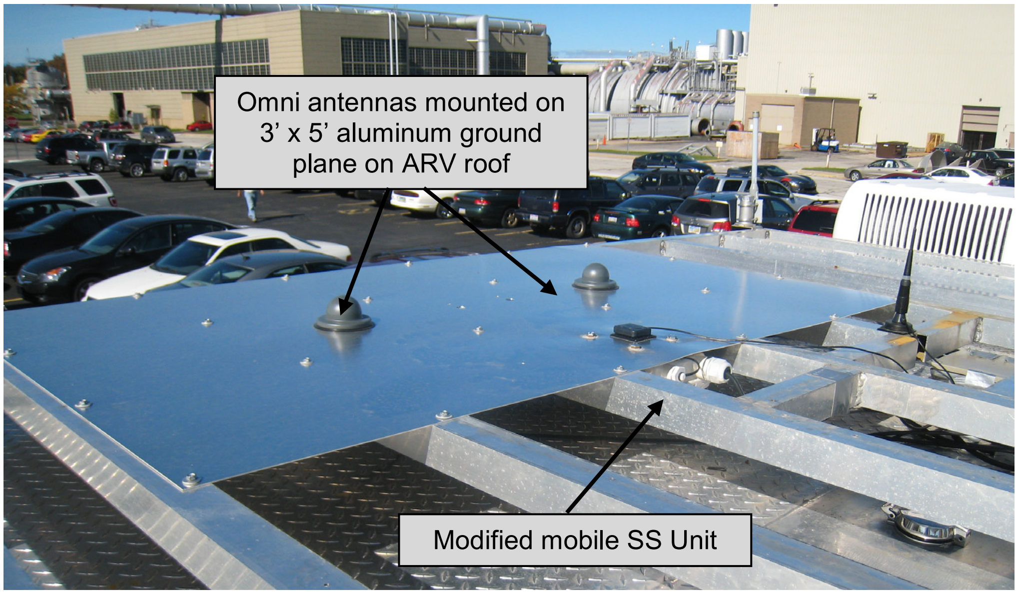


Figure 25.—Two Omni AeroMACS antennas mounted on a ground plane on the AeroMACS Research Vehicle (ARV) for mobility tests.

The 5 by 3 ft (1.5 by 0.9 m) aluminum ground plane plate is mounted on an aluminum truss structure on top of the ARV. The plate’s size was chosen to provide a ground plane distance from each antenna to the plate’s edge that meets or exceeds the ground plane size used for the reference antenna patterns provided by Huber-Suhner. This minimum distance condition is met for antenna-to-antenna spacing of up to 10 wavelengths when antennas are used in the dual-antenna MIMO configuration

The ARV cargo box provides seating and workspace for staff while running mobility tests. Electronic equipment is mounted in this area to support AeroMACS tests and data recording. The work space, electronics enclosures, and test instruments are shown in Figure 26.

Figure 26.—NASA AeroMACS Research Vehicle (ARV) crew and instrument area.

A diagram of the mobile AeroMACS network mounted in the ARV is illustrated in Figure 27 as an overlay of the ARV. The network is comprised of one or two AeroMACS antennas, a SS mobile unit, a power over Ethernet (PoE) power injector, a 5-port network switch, and a SBC. The SBC host IxChariot test software used for AeroMACS network performance evaluation.

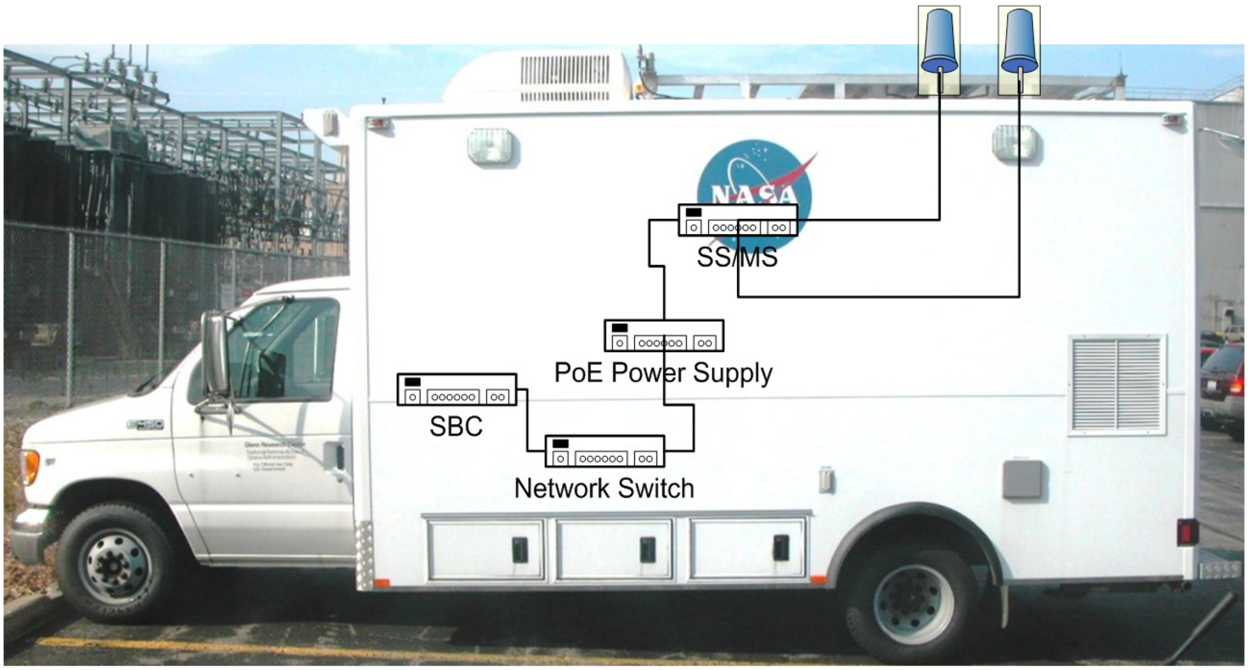


Figure 27.—NASA AeroMACS Research Vehicle (ARV) logical network.

The ARV is suitable for mobility tests and was escorted by the FAA (Figure 28) to a variety of locations on the airport surface to perform those tests, including runways (Figure 29), taxiways (Figure 30), ramp area (Figure 31), deicing area (Figure 32), and perimeter roads (Figure 33).

Figure 28.—Federal Aviation Administration vehicle escorting the AeroMACS Research Vehicle (ARV) on CLE airport surface.

Figure 29.—AeroMACS Research Vehicle (ARV) being escorted onto CLE runways.

Figure 30.—AeroMACS Research Vehicle (ARV) being escorted along CLE taxiways.

Figure 31.—AeroMACS Research Vehicle (ARV) being escorted on CLE ramp areas.

Figure 32.—AeroMACS Research Vehicle (ARV) being escorted onto CLE deicing pad.

Figure 33.—AeroMACS Research Vehicle (ARV) being escorted along CLE perimeter road.

Multiple mobility tests were performed on runways of the CLE airport with FAA escort and speeds of 50 kt or greater were achieved. A 50-kt speed is established as the maximum mobile speed for airport drive tests for the following reasons:

(1) 40 kt was established during RTCA SC–223 discussions as the maximum taxi speed thought to occur at a commercial airport
(2) An operating margin of 10 kt was requested by EUROCAE

Drive tests were also performed on service roads and taxiways at lower speeds, typically 25 kt. Analysis of the drive test results are provided in the following sections.

3.2.2.3 Test Results

3.2.2.3.1 Runway Drive Tests

Multiple drive tests were conducted during Phase II at the CLE airport using the NASA ARV. Drive paths included active and nonactive areas of the airport surface, including normally active runways, taxiways, and service roads. Drive tests were conducted with an accompanying FAA vehicle and staff member for clearance and safety reasons. Three tests analyzed in this section provide insight into mobility handoff and antenna configuration performance.

(1) Runway 24L/6R drive tests on October 12, 2010
(2) Service road drive test on November 4, 2010
(3) Nonactive movement area and service road drive tests on December 16, 2010

ARV Drive Tests Conducted October 12, 2010

The first series of mobile AeroMACS drive tests in the US was conducted using the NASA ARV at the CLE airport on runway 24L/6R on October 12, 2010, as shown in Figure 34. Drive speed was nominally 40 kt. Tests were conducted with the mobile SS antenna system in MIMO and SISO modes. Network performance was evaluated by generation of bidirectional traffic using IxChariot test software. AeroMACS radio and network parameters were set up according to Section B.2.2 of the Task 7-1 Phase II Test Plan in Appendix B.

Figure 34.—AeroMACS Research Vehicle (ARV) being escorted on Runway 24L heading southwest.

Runway 24L is 9955 ft (approximately 3 km) in length, providing an opportunity to test AeroMACS air link ranges up to approximately 1 mi (1.6 km). In addition to reduced signal strength caused by increased range, signal strengths are also reduced by the antenna gain rolloff of the sectorized BS antenna.

The positions of BS1 and BS2 relative to runway 24L/6R are marked in Figure 35. The sector antenna pointing directions are indicated by arrows for the BTS sectors (two for BS1 and three for BS 2). The BTS sector antennas have a 90° half-power (3 dB) beamwidth. The approximate –3-dB boundaries are indicated in Figure 35 with dashed lines for the two sectors used most often in these tests. The ARV travelling along runway 24L in the southwest (SW) direction experienced varying signal levels from a combined effect of range changes and BS sector antenna gain variation as the aspect angle changes.

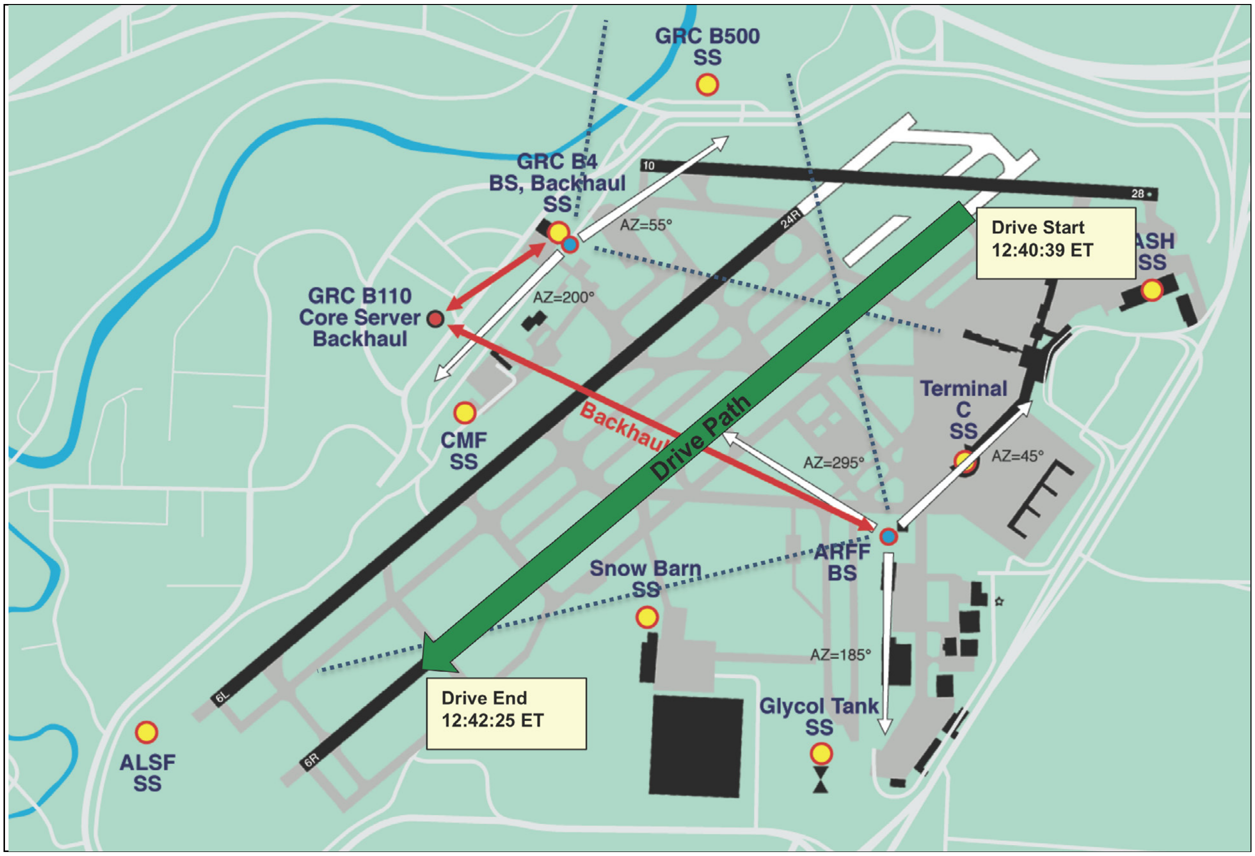


Figure 35.—NASA ARV Drive Test, Runway 24L ARV Position VS Time (GMT); Speed = 40 kt (46 mph, 74 kph), Oct. 12, 1640 GMT. Acronyms are defined in Appendix A.

A plot of DL throughput during an ARV drive test along runway 24L from northeast (NE) to SW is shown in Figure 35. The antenna configuration during this test is 2×1 MIMO (2 receive antennas, 1 transmit antenna) at the mobile unit. The base station antenna configuration is 2×2 MIMO (2 receive antennas, 2 transmit antennas). The DL direction has the advantage of 2-antenna receive diversity, while the UL is single-antenna only. Therefore, the impact of MIMO on throughput was studied on the DL.

The highest average throughput expected on DL in a 5 MHz channel is 7.5 Mbps, which was achieved midway through the drive test. This corresponds to QAM64 modulation, the highest-order modulation supported by the standard.

The IEEE 802.16–2009 standard specifies an adaptive modulation feature for the SS that adapts the modulation rate according to link conditions with the goal of adjusting data throughput to the highest level supportable by current link conditions. Test traffic throughput was reduced at the start and finish of the drive path, consistent with reduced modulation rate because of added propagation loss and BS sector antenna gain global.

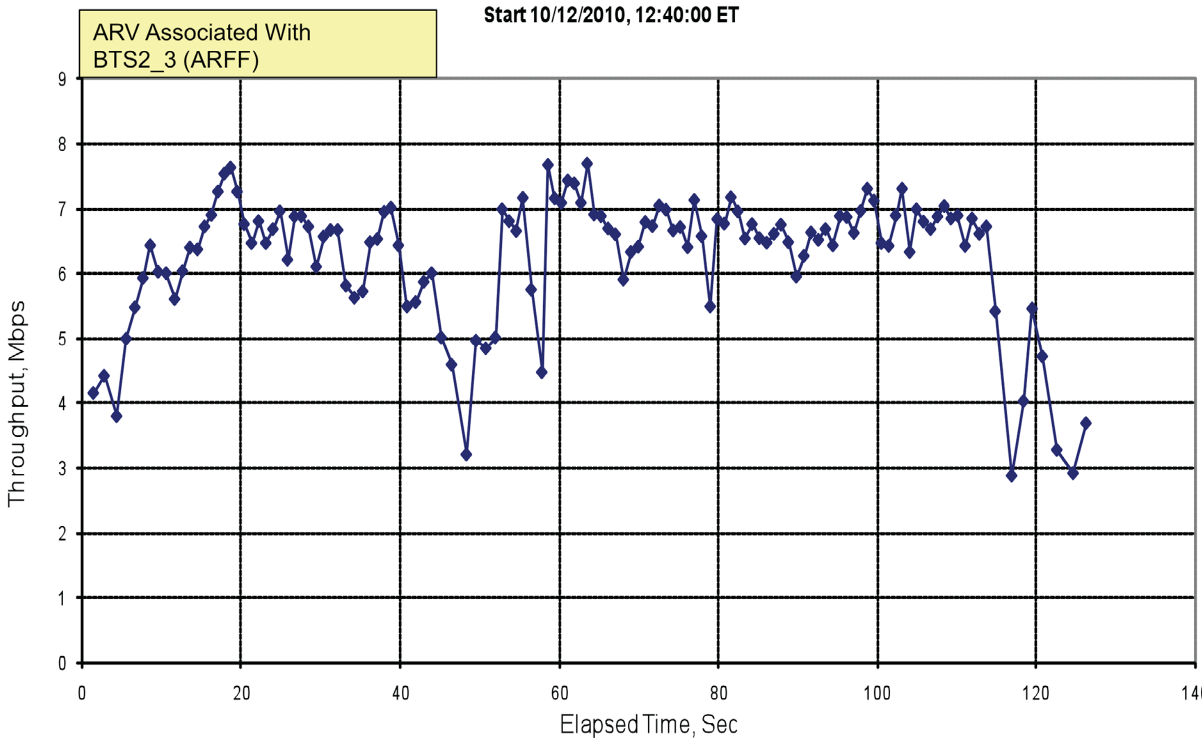


Figure 36.—NASA ARV Drive Test, Runway 24L; DL throughput along drive path, Mbps; Speed = 40 kt (46 mph, 74 kph); MIMO antenna mode; Oct. 12, 1640 GMT. Acronyms are defined in Appendix A.

Figure 36 is a plot of DL throughput during an ARV drive test along runway 24L from NE to SW with a SISO antenna configuration (1 receive antennas, 1 transmit antenna) at the mobile unit. The base station remained 2 by 2 MIMO (2 receive antennas, 2 transmit antennas).

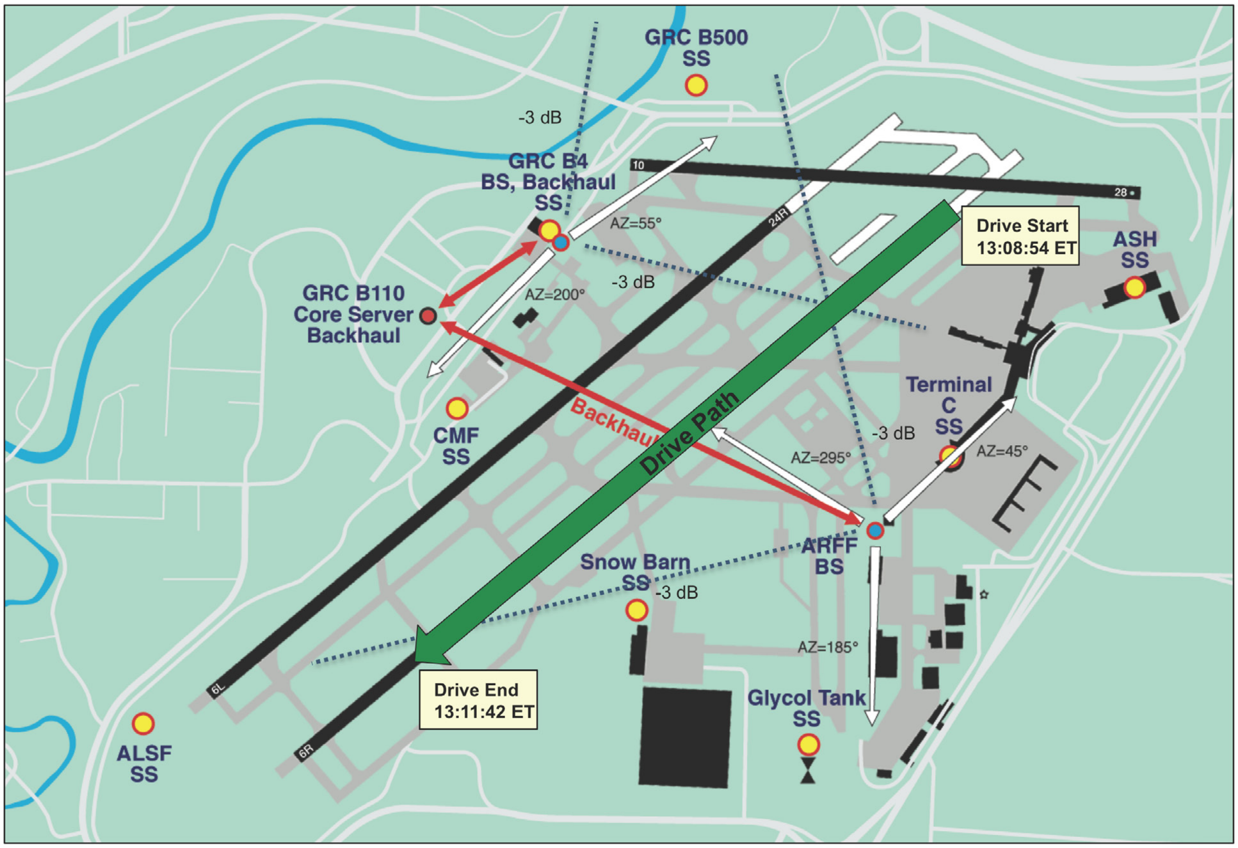


Figure 37.—NASA ARV Drive Test, Runway 24L; ARV Position VS Time (GMT); Speed = 40 kt (46 mph, 74 kph) SISO antenna mode, Oct. 12, 1708 GMT. Acronyms are defined in Appendix A.

The throughput plot of Figure 37 includes the results of two drive tests, both in the SISO antenna mode. One drive test was for the path described in Figure 37 in which the ARV SS was receiving service from BTS2 3. A shortened SISO drive test followed the same path. The ARV SS was associated with BTS1-2 throughout this test. The test results are plotted on a common normalized distance scale.

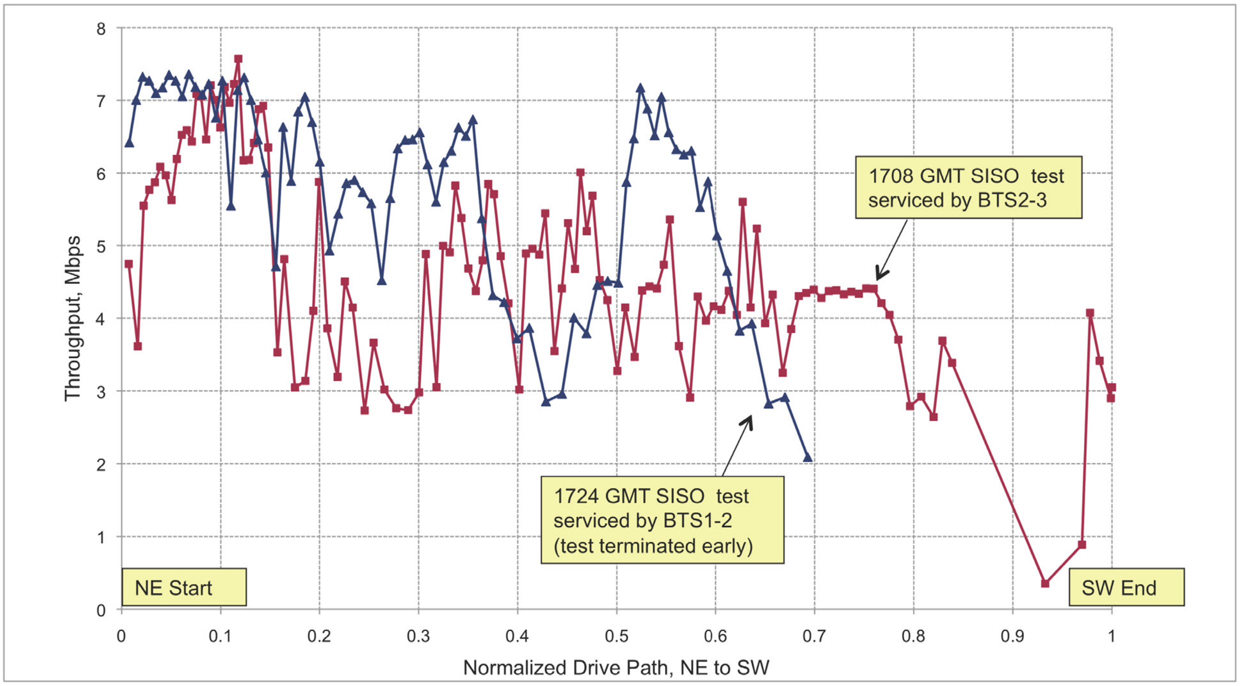


Figure 38.—NASA ARV Drive Test, Runway 24L; DL throughput along drive path, Mbps; Speed = 40 kt (46 mph, 74 kph); SISO antenna mode; Oct. 12, 1708 and 1724 GMT. Acronyms are defined in Appendix A.

The plot in Figure 38 compares the throughput performance of MIMO and SISO antenna configurations along the same drive path and for service provided by BTS2-3 in both cases. Results from the 1640 GMT MIMO test and the 1708 GMT SISO test are shown. A comparison of MIMO versus SISO throughput along the drive path shows that the MIMO antenna configuration achieved greater average throughput. Throughput averaged over the drive tests for MIMO and SISO antenna configurations are compared numerically in Figure 39.

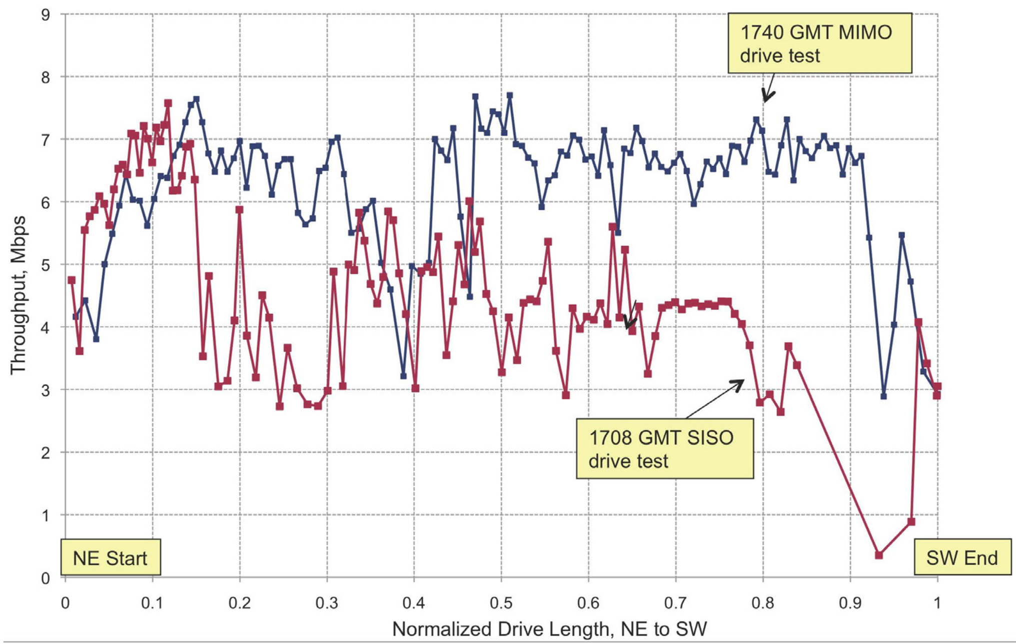


Figure 39.—NASA ARV Drive Test, Runway 24L; DL throughput along drive path, Mbps; Speed = 40 kt (46 mph, 74 kph); MIMO and SISO antenna mode comparison; 1640 GMT MIMO, 1708 GMT SISO. Acronyms are defined in Appendix A.

TABLE 12.—MIMO AND SISO MOBILE ANTENNA CONFIGURATION THROUGHPUT COMPARISON
[Acronyms are defined in Appendix A.]

Test time	Antenna mode	Throughput average, Mbps	Throughput minimum, Mbps	Throughput maximum, Mbps
1640 GMT 10/12/10	MIMO	5.13	2.70	7.70
1708 GMT 10/12/10	SISO	3.89	0.35	7.57

ARV Drive Tests Conducted December 16

A series of drive tests were conducted in the nonmovement area near CLE Terminals C and D as shown in Figure 40. Figure 41 is an enlargement of the drive test area with four drive paths shown. Two of the tests were performed with the AeroMACS SS antenna in a two-antenna MIMO configuration, and two tests had a single-antenna SISO configuration.

The AeroMACS signal characteristics in this drive test area can be described as strong signal and high multipath. The strong signal occurs because of the close proximity to BS2. High multipath is caused by reflections from nearby structures; mostly from Terminals C and D.

Figure 40.—AeroMACS Research Vehicle (ARV) being escorted around gates between along CLE Terminals C and D.

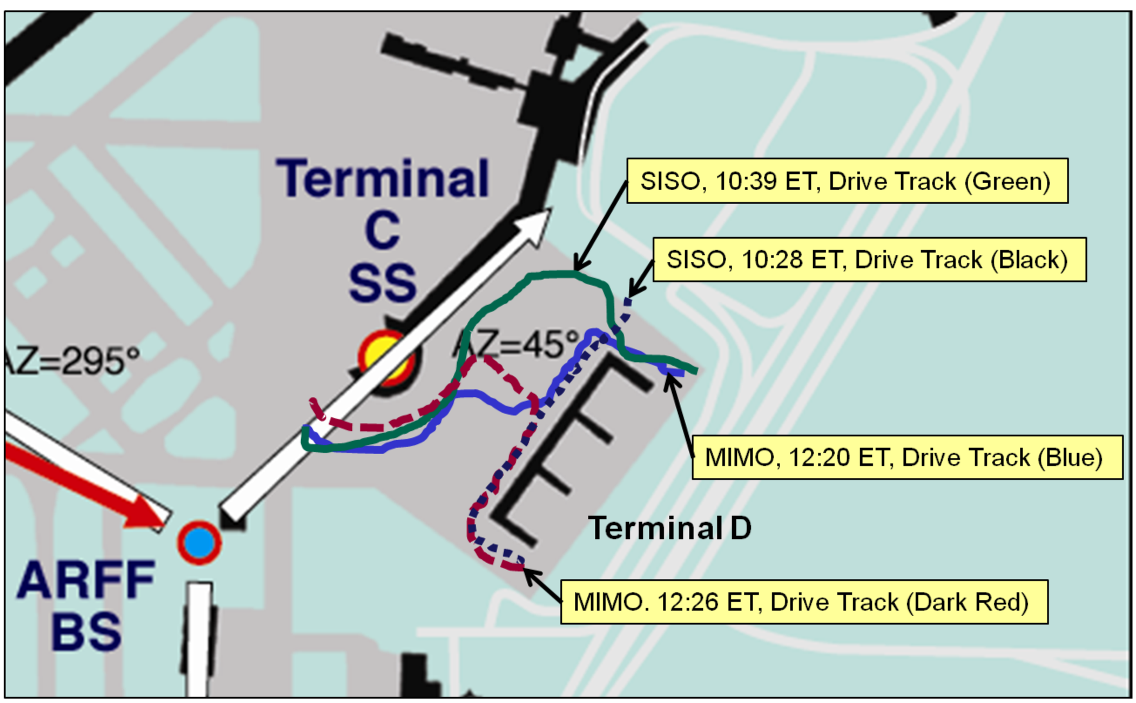


Figure 41.—Nonmovement area drive tests near Terminals C and D. Acronyms are defined in Appendix A.

Figure 42 is a plot of DL traffic throughput rate from BS2 to ARV during the four drive tests. Traffic streams were generated with IxChariot software. The MIMO antenna configuration implemented in two drive tests resulted in nominal traffic throughput rates of 6 Mbps with brief rate variations.

The two test drive tests with SISO antenna configuration resulted performance that varied markedly from the MIMO configuration. A throughput rate of 6 Mbps is achieved for periods of time, separated by longer periods of reduced rate caused by degraded RF link conditions. In addition, the throughput rate is disrupted during multiple initiations of the BTS sector handover process that always resulted in the ARV SS returning to the originally serving sector (BTS 1-1) with no resulting handover. These disturbances to traffic throughput during SISO tests resulted in the throughput rate tests of the 10:28 ET drive test terminating early because of connection timeouts in the IxChariot test software.

BTS handover periods can be identified on the chart below by the throughput rate dips to nearly zero in two of the four cases plotted in Figure 42. The traffic flow is interrupted during the handover process because the handover algorithm implemented during these tests breaks the serving BTS connection before establishing a new connection. The version of SS and BS firmware implemented at the time of these tests did not support hard handover (HH) or fast base station switching (FBSS) operation and therefore required tens of seconds to complete. The handover process resulted in the ARV SS returning to the original serving BS sector, BTS 2-1, for all of the handover attempts during these two SISO tests. One handover attempt was initiated during the SISO drive test at 10:28 ET and the SISO drive test at 10:39 ET had five handover attempts, all resulting in no change to the serving BTS sector. These handover attempts can be observed in log files recorded by the Alvaristar BTS management software.

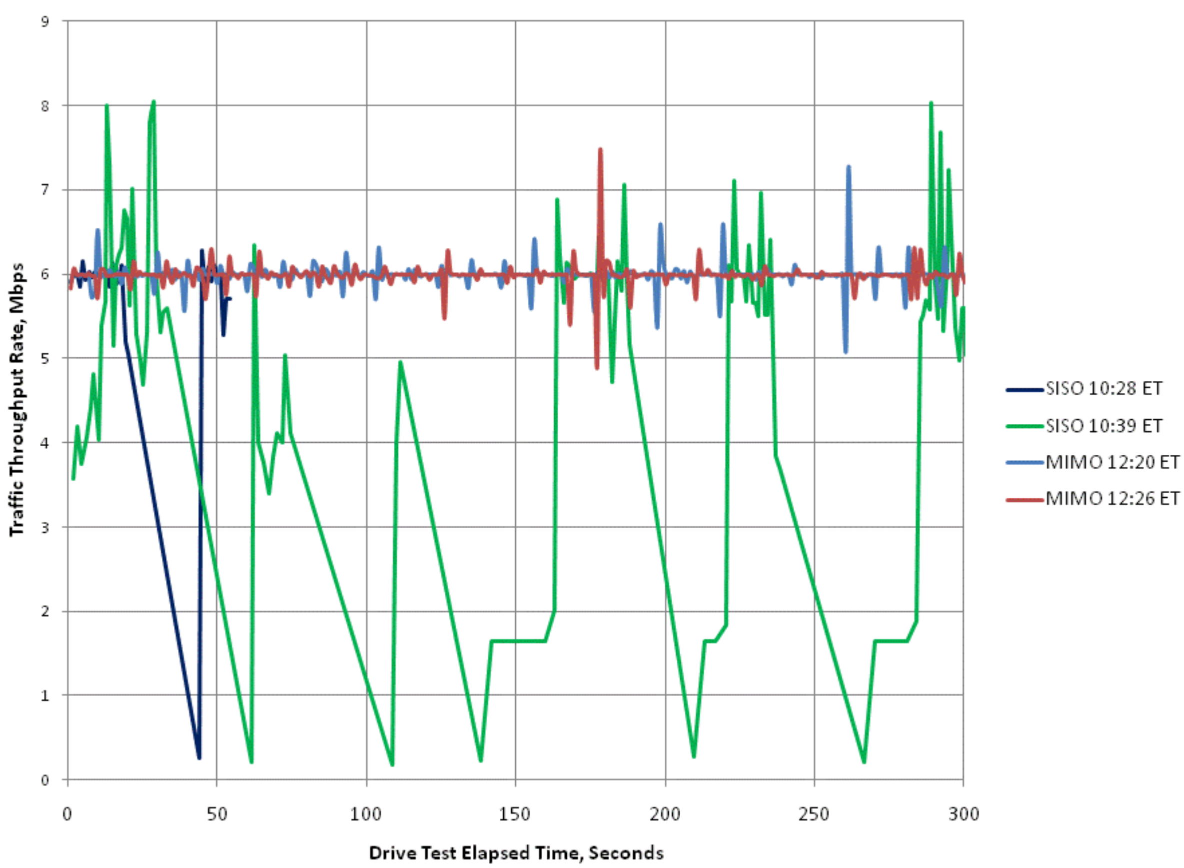


Figure 42.—Traffic throughput rate during drive tests near Terminals C and D.

3.2.2.4 Drive Test Observations

The following observations are derived from the ARV drive tests on runway 24L at a speed of 40 kt.

3.2.2.4.1 BS Sector Associations

The BTS sector serving the ARV SS at the beginning of the drive tests that were analyzed in this report consistently provided service throughout the entire drive path with no handovers to another sector. This occurred although the ARV SS moved from the BS sector mainlobe region, past the pattern –3 dB position and into sidelobe and backlobe regions. Further, the initial BTS sector association was held although the ARV SS moved through regions where another BTS sector provided higher RSSI.

Specifically, the drive test of 1640 GMT on runway 24L shown in Figure 37 began with BTS2-3 as the serving sector although it was outside of that sector's main pattern and within the main pattern on BTS1-2. The same handover performance was observed for the SISO drive test. BTS2-3 continued as the serving sector through both drive tests.

The decision algorithm to select the serving BTS sector is not fully defined by the IEEE 802.16–2009 standard; rather it is left up to the developer to develop an algorithm that best suits the intended market. Most algorithms implement a threshold value for difference in signal quality between the serving sector and other available sectors. This threshold must be exceeded before the handover process is initiated and provides a "hysteresis" effect that prevents a mobile SS from being bounced back and forth between BTS sectors in a transition region. The threshold level is a design parameter. While BTS handovers that changed the serving BS sector have been observed during other drive tests, these tests show that the AeroMACS equipment installed in the NASA Glenn prototype test bed tends to hold the current BTS connection and not initiate handover of the serving BTS connection. Handover algorithm design and parameter settings will impact average traffic throughput for a mobile SS, and therefore it impacts the required BTS transmitter power levels. Design of the algorithm and parameter settings should be studied further as future drive tests provide additional performance data. This is a study area that potentially could provide a payoff of improved mobile station throughput, reduced transmitter power, and increased margin against co-user interference.

3.2.2.4.2 MIMO Versus SISO Performance

The runway 24L/6R tests provide an initial assessment of mobile station antenna configuration impact on performance. Drive tests were conducted with MIMO and SISO antenna configurations. Figure 39 compares mobile SS DL throughput performance for MIMO and SISO test runs. Table 12 compares the throughput performance averaged over the full drive path. The advantage of a two-antenna MIMO configuration is apparent with this comparison.

Additional MIMO versus SISO comparisons can be drawn from the December 16 drive tests in the area near Terminals C and D. This high-signal-strength, high-multipath signal environment provided a sharp contrast in performance between two drive tests with a two-antenna MIMO antenna configuration on the ARV compared to a single-antenna SISO configuration as can be observed in Figure 42. The SISO configuration resulted in lower link performance with periods of lower traffic throughput rate, and caused the AeroMACS network to attempt multiple BTS sector handovers that cause additional disruption of traffic throughput.

The MIMO drive tests provide information on a unique antenna combination. The BTS antenna configuration is 2×2 MIMO in the AeroMACS prototype. Two antennas are arranged orthogonally to provide dual 45° slant polarization relative to the ground horizon. This test configuration represents a realistic scenario where BTS antennas use 45° slant polarization to be compact, and the SS antennas are spatially separated on a ground plane as they will be for an aircraft installation.

3.2.3 Test Case 3, Channelization Tests

3.2.3.1 Test Objectives

The goal of the adjacent channel tests was to evaluate the need to allocate a guard band between AeroMACS channels to prevent adjacent-channel interference from reducing channel throughput. The between-channel guard band is in addition to the guard band implemented in the IEEE 802.16–2009 standard by suppression of subcarriers at the channel edges. A complete discussion of the use of in-band guard bands is provided in Section 6.2.2.3.2 of Volume I of this report.

3.2.3.2 Test Method

Adjacent channel tests were completed using the fixed-position SS sites in the NASA Glenn AeroMACS prototype. Figure 43 shows positions of the SS sites chosen for the test.

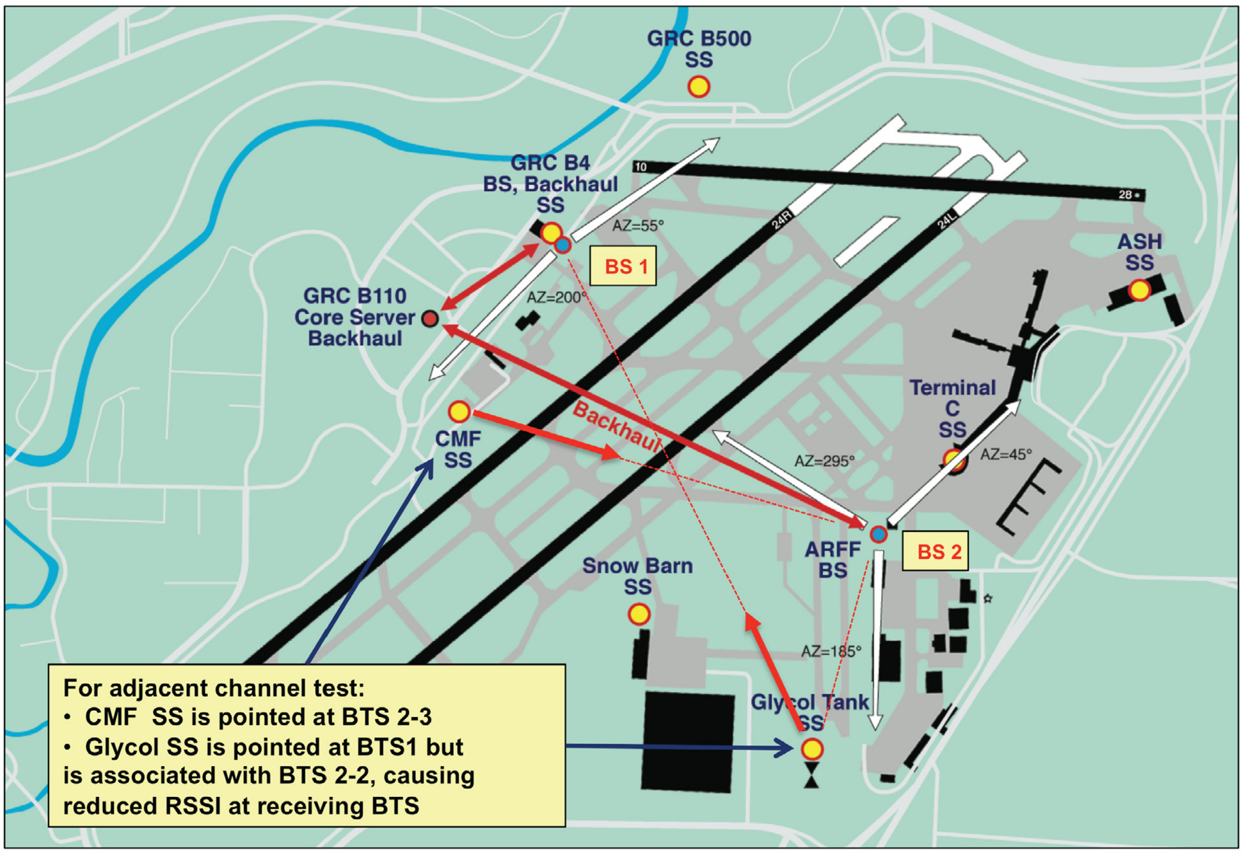


Figure 43.—Connectivity for adjacent channel test case.

BTS 2-1 and BTS 2-3 sectors were used in this test for adjacent channels. BTS2-3 was set at a center frequency of 5100 MHz. BTS 2-1 was set to 5105 MHz for the adjacent channel test and 5115 MHz for the nonadjacent channel test. The nonadjacent channel test provided a comparison between adjacent channel performance and performance with the second channel separated by 10 MHz (two channel widths).

Additional real-world factors affected this test. First, the glycol tank's SS, with its built-in directional antenna, is pointed at BS1 instead of BS2 that BTS2-1 is within. The off-pointing of that SS reduces its RSSI at BTS2-1, reducing its link quality and the throughput achieved. The lower RSSI also makes this link more susceptible to adjacent-channel interference.

Secondly, the CMF SS is positioned so that its signal arrives in the reduced-gain sidelobe region of BTS2-1. This antenna response reduces adjacent channel interference when combined with the reduced subcarrier guard-band feature built into the AeroMACS channel structure as discussed in Volume I.

The test was performed by recording the highest traffic throughput rates achieved between Glycol SS and BTS2-3 under the following interference conditions:

(1) No signal radiated at the adjacent channel from the CMF SS
(2) Adjacent channel signals with CMF SS loaded at full data throughput, UL and DL
(3) CMF SS loaded at full data throughput, UL and DL, and centered 10 MHz above the Glycol SS channel

3.2.3.3 Test Results

Results of the adjacent channel test are shown in Figure 44 with the adjacent channel not radiating, labeled as "Before CMF," and with the adjacent channel active, labeled "After CMF." A slight difference in throughput is observed in the DL direction when the adjacent channel is active. The measured change was approximately 0.1 Mbps, which is a 2 percent reduction in throughput with an active adjacent channel. No impact on UL was observed.

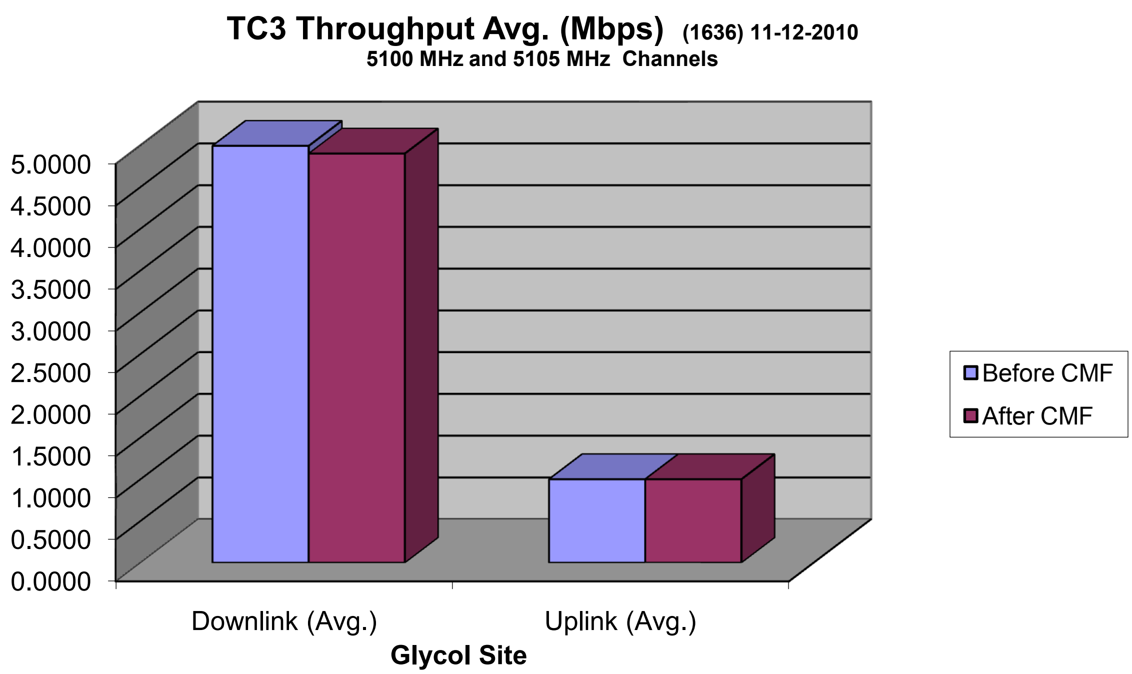


Figure 44.—Glycol SS to BTS 2-1 average throughput, Mbps. Acronyms are defined in Appendix A.

The adjacent channel test was repeated with the interfering channel separated from the test channel by 10 MHz and not active, labeled as "Before CMF," and with the adjacent channel separated by 10 MHz and active, labeled "After CMF" in Figure 44. Again, a small impact on DL channel throughput is observed. The effect was approximately 1 percent reduction of throughput, which is a smaller impact than when the channels were adjacent in frequency.

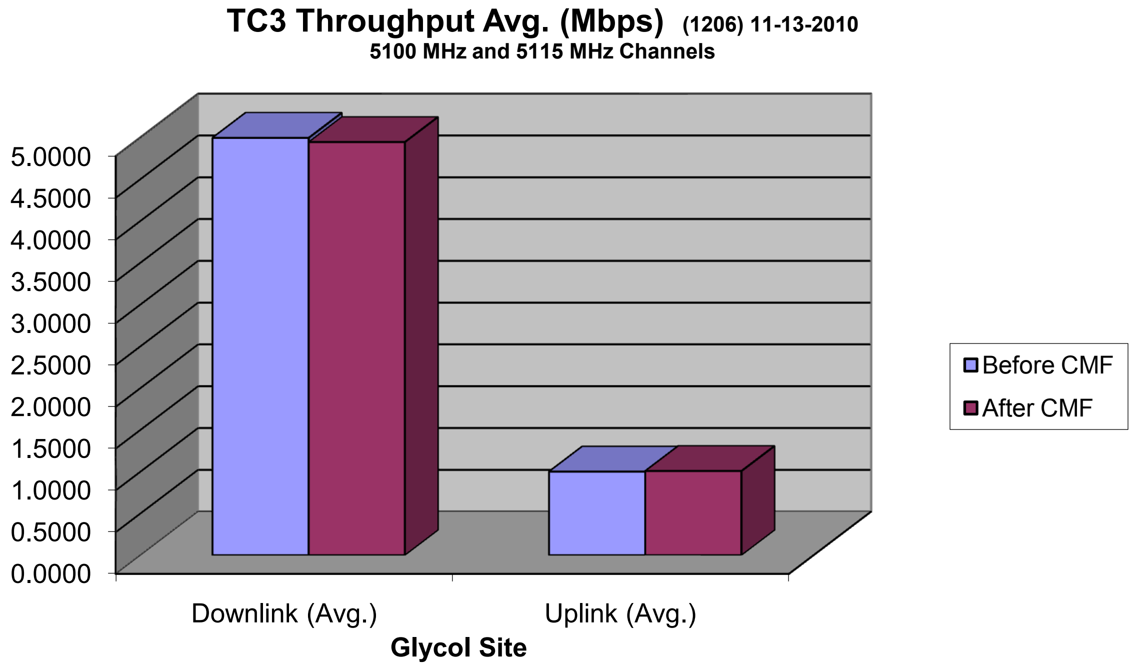


Figure 45.—Glycol SS to BTS 2-1 average throughput with 10-MHz channel separation, Mbps. Acronyms are defined in Appendix A.

3.2.3.4 Adjacent Channel Test Observations

The performance of an AeroMACS link between a BS and a SS operating in a bi-directional UL and DL mode was evaluated for impact of an active channel operating at an adjacent frequency allocation. Adjacent channel interference performance was aided by BS sector antenna factor rejection that is expected in an operational network layout. A minor (2 percent) traffic throughput rate change was observed when an active adjacent channel was present. The impact was reduced by 1 percent when the second channel was moved 10 MHz away. These impact values are much less than a 50 percent aggregate throughput reduction that would result with use of 5-MHz guard band allocations between channels. These results support a recommendation that no allocation of additional guard band is needed between AeroMACS channels to suppress adjacent channel interference.

3.2.4 Test Case 4, Transmit Power Requirements

3.2.4.1 Test Objectives

Initial recommendations for AeroMACS transmit power levels were formulated based on results from drive tests at the CLE airport. Transmit power level requirements were evaluated through a series of drive tests with the mobile ARV SS. Transmit power levels must be chosen to provide communication coverage across an airport surface while also minimizing potential interference to co-allocated users of the AM(R)S 5091- to 5150-MHz band.

3.2.4.2 Test Method

Base station signal strength on the airport surface was surveyed and recorded in a variety of conditions including range, MIMO and SISO antenna configuration, various aspect angles relative to the BS, into NLOS shadow conditions, and in regions of high multipath. These conditions were attained by driving the NASA ARV van on runways, service roads, and into terminal ramp regions, for example close to terminal building structures as shown in Figure 46.

Figure 46.—Aeronautical Research Vehicle being escorted into areas of non-line-of-sight shadow conditions and high multipath reflections.

Signal strengths were recorded for later analysis using a number of methods. SS readings of RSSI and CINR were recorded at approximately one-second intervals from the ARV SS. Second, the YellowFin[7] instrument was used to record measurements of RSSI and CINR using a 0 dBi antenna mounted on the ARV roof. Finally, IxChariot-generated DL traffic throughput was recorded for a measurement of signal quality. The position of the ARV was recorded during the drive test by logging GPS waypoints reported by the YellowFin.

The survey of BS signal strength across the airport surface was used to assess whether adequate signal is radiated by the BSs. The signal strength survey was completed with a BS transmit power of +20 dBm (100 mW) to provide a benchmark level.

[7] YellowFin is a product of Berkeley Veritronics Systems, Inc., 255 Liberty Street, Metuchen, NJ 08840, USA.

3.2.4.3 Test Results

Drive tests were conducted on October 12, 2010, for Test Case 2. Test results were described in Section 3.2.2.3. The results are further analyzed in this section for their implications for BTS transmit power requirements. This provides an initial assessment of transmit power requirements based on the performance of a mobile unit tested on one runway. Additional analysis should be completed with future test data under additional drive test conditions.

The ARV drive path driven at 1640 GMT is shown in Figure 47 with link distances shown from BS2 to the start and end positions for the drive. The end of the drive provides the longest path distance of 5620 ft (1712 m).

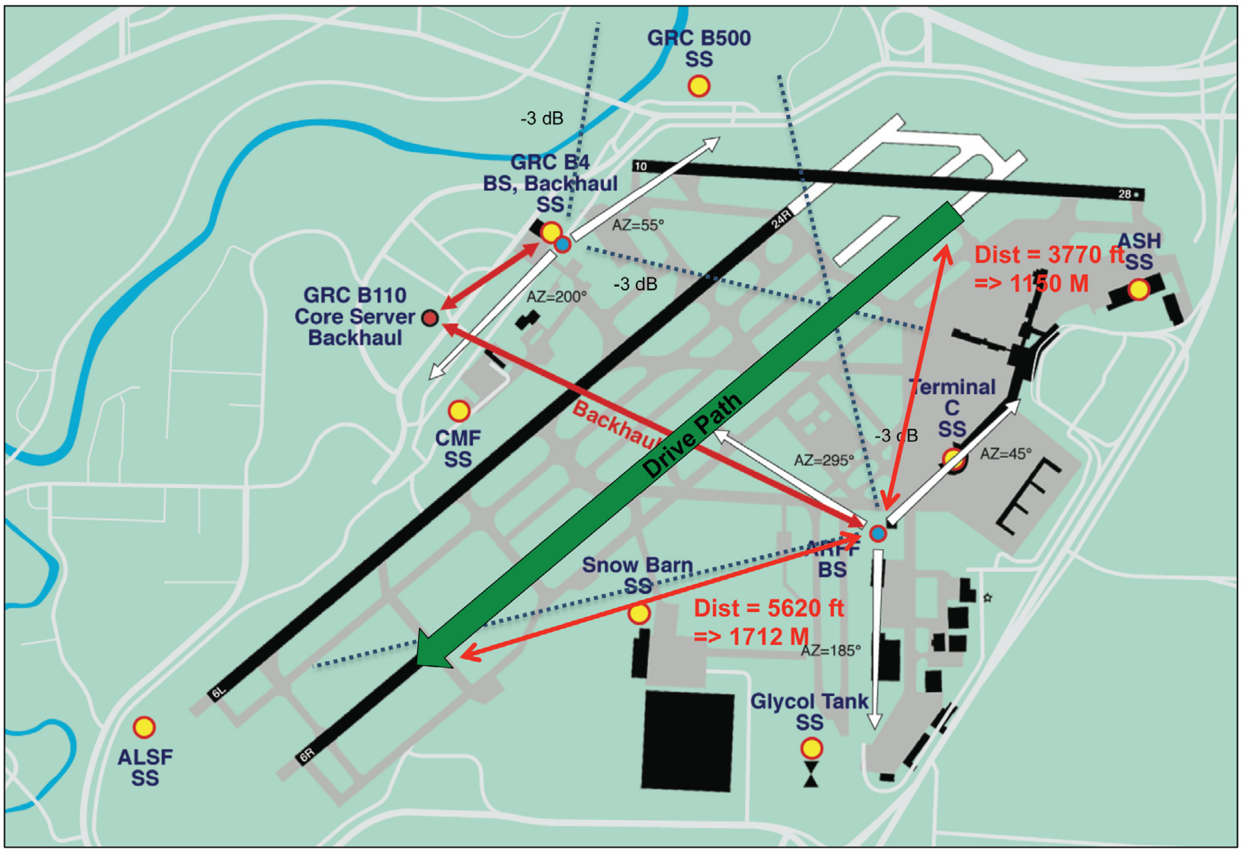


Figure 47.—Runway 24L drive path with distances.

Receive signal strength is a function of the link distance and BTS sector antenna gain. Real-time RSSI values for the ARV SS are available to be read from the terminal unit on a periodic basis. RSSI values read from the SS are plotted in Figure 48, overlaid with data throughput measurements computed by IxChariot. Correlation between SS RSSI and throughput rate can be observed with higher RSSI readings (less negative) generally yielding higher throughput rate.

The YellowFin receiver provides another method of RSSI measurement. The YellowFin instrument is programmed to scan through the AM(R)S frequency range searching for valid BS transmissions. RSSI is recorded with reference to the BS center frequency when a valid BS transmission is detected. BS transmissions are received through a 0 dBi gain antenna mounted on the roof of the ARV.

The ARV SS maintained service from BTS2-3 throughout the 1640 GMT drive test. RSSI values recorded by the YellowFin at the BTS2-3 frequency of 5100 MHz are plotted in Figure 48. Again, a correlation can be observed between YellowFin and ARV SS measured RSSI and throughput rate derived by IxChariot. Lower RSSI readings from the YellowFin compared to the SS readings can be attributed to its lower receive antenna gain of 0 dBi compared to 8 dBi for the ARV antenna.

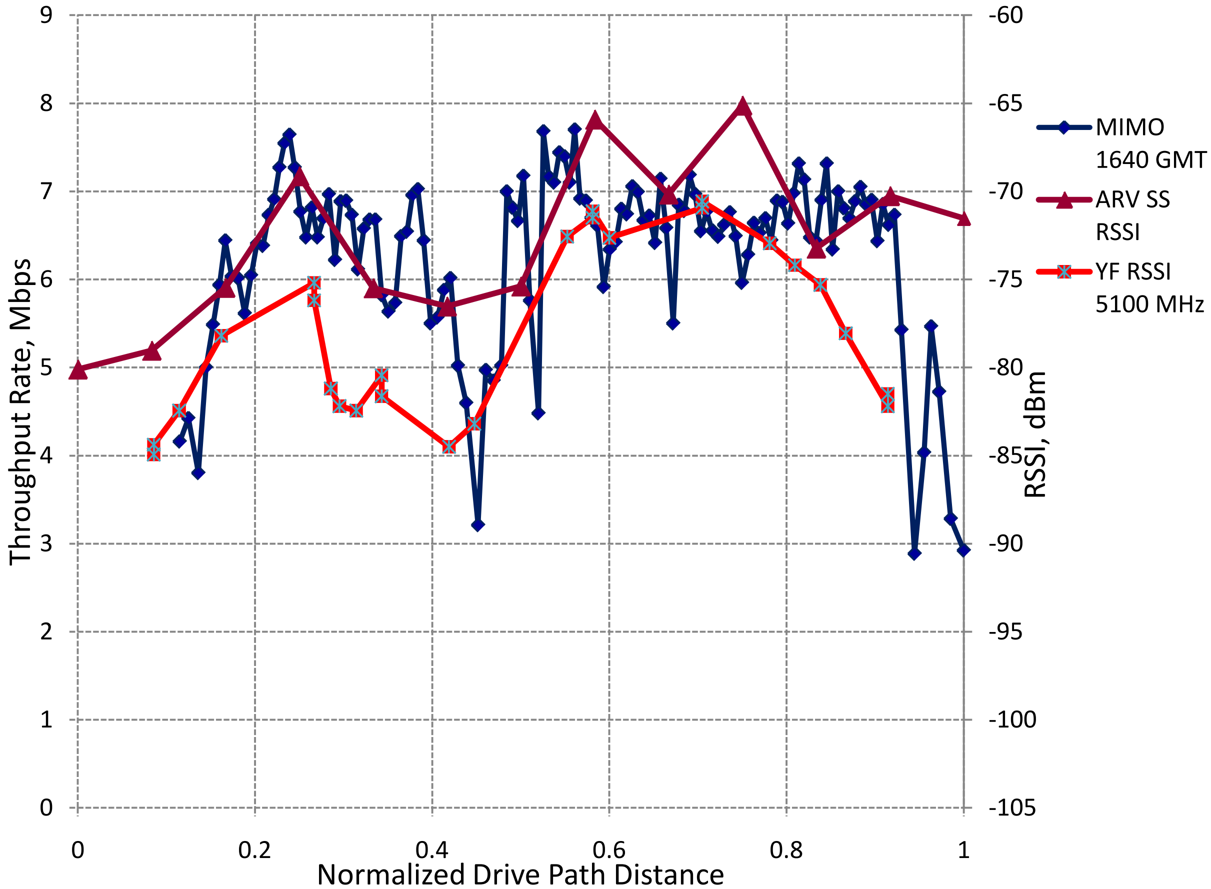


Figure 48.—Runway 24L drive test received signal strength indication (RSSI) and throughput.

A few interesting performance characteristics can be observed in as follows:

(1) Throughput rate was reduced as expected at the drive path start and end where lower signal strength occurred because of increased link path loss and decreased BTS sector antenna gain
(2) DL throughput reached a rate of 7.5 Mbps, the highest rate expected for a 5-MHz channel bandwidth, 60/40 percent TDD ratio, and MIMO Matrix A antenna configuration.
(3) RSSI readings from the ARV SS and the YellowFin decreased and hence the throughput rate decreased unexpectedly from 20 to 50 percent of the drive path. The cause of this reduced RSSI is unknown; it might be caused by an unwanted variation the BTS sector antenna pattern.
(4) A minimum throughput rate of 3 Mbps was maintained over the length of Runway 24L. This included a maximum link path of 7320 ft (2.2 km) at the –3 dB BTS sector pattern.
(5) Link connectivity was maintained at vehicle speeds of at least 40 kt (46 mph, 74 kph).

An ARV drive test completed on December 16, 2010, provides additional insight into AeroMACS link performance. The ARV was driven on a taxiway and service road around the southwest end of runway 24L/6R on the path shown in Figure 49 and Figure 50. The ARV antenna system was in a two-antenna MIMO configuration, and the ARV SS was connected to BTS 1-1 during the test. The maximum link distance from BS1 to the ARV was 2.15 km.

Figure 51 provides a plot of DL test traffic throughput rate from BS1 to the ARV during this 5-min segment of the drive path. A nominal throughput rate of 6 Mbps was maintained during the test. BTS 1-1 sector was maintained as the serving sector without attempts to handover to another BTS sector. This throughput rate corresponds to a modulation mode of QAM 64 CTC-2/3 for the hardware implemented in the NASA Glenn prototype test bed.

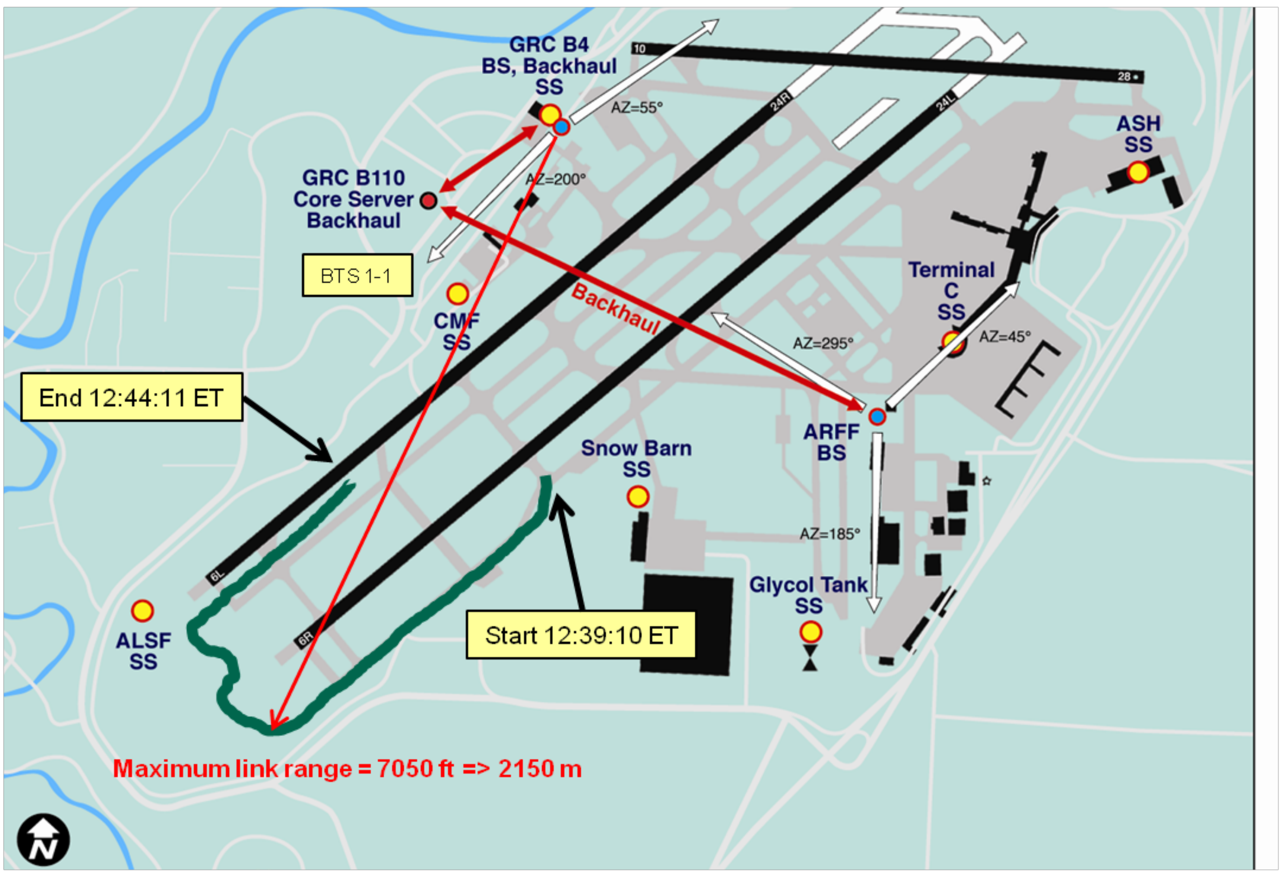


Figure 49.—ARV drive test in MIMO mode, December 16, 2010. Acronyms are defined in Appendix A.

Figure 50.—Aeronautical Research Vehicle being escorted around the southwest end of runway 24L/6R.

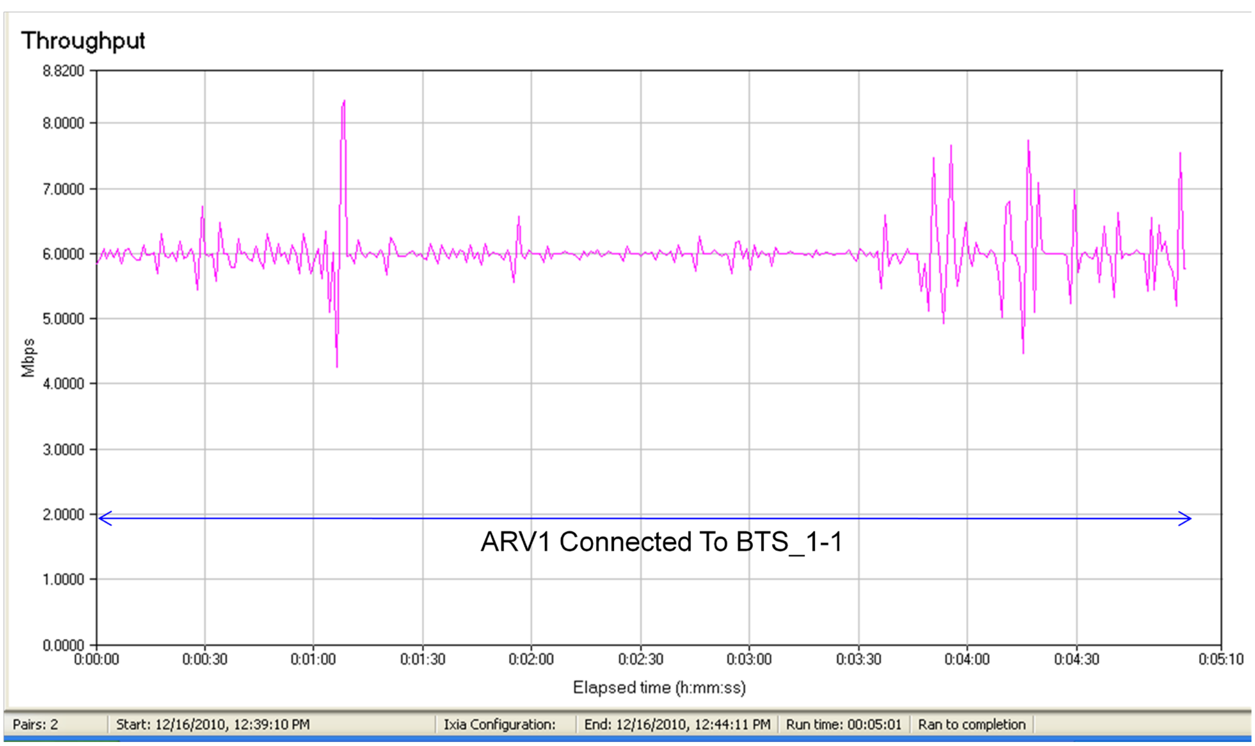


Figure 51.—Traffic throughput rate, ARV drive test in MIMO mode, December 16, 2010. Acronyms are defined in Appendix A.

3.2.4.4 Transmit Power Requirements Observations

The operating conditions of the NASA Glenn prototype test bed in Cleveland provided a DL throughput rate of at least 3 Mbps for a range of approximately 1 mile (1.6 km) for the following conditions:

(1) Clear line of sight from BS2 to ARV SS on runway 24L
(2) BTS sector transmit power: +20 dBm (100 mW) per MIMO channel
(3) BTS sector: 2×2 MIMO, mode A
(4) ARV SS: 2×1 MIMO, mode A
(5) BTS sector antenna gain: +16 dBi
(6) ARV SS antenna gain: +8 dBi

The drive test on runway 24L/6R established that a reasonable traffic throughput and range can be established with 100 mW BTS transmitter power under benign link conditions. A drive test on December 16, 2010, established that a high-rate modulation can be maintained at a greater range of 2.1 km. Additional tests and analysis need to be completed to assure that this power level supports links into areas of higher signal multipath and non-line-of-sight conditions.

3.3 Experiment and Test Plan to Validate Tradeoff Space and Application Support

The NASA–CLE CNS Test Bed, modified to include an AeroMACS communications network, will be used to evaluate various combinations of parameters within the IEEE 802.16 standard in order to validate the tradeoff space for an AeroMACS profile. The airport surface presents a unique combination of areas of open terrain around the runways, which have few obstacles to cause multipath and signal diffraction, and terminal and building areas, which have high levels of multipath dispersion and diffraction. Added to these contrasting propagation environments is the operation of AeroMACS at the upper end of the IEEE 802.16–2009 frequency span of 2 to 6 GHz, where signal wavelengths are shorter and multipath effects are increased.

Table 13 presents a collection of test cases designed to evaluate AeroMACS parameters in the airport environment. The “Design tradeoff category” column defines broad parameter categories, whereas the “Parameters” column lists detailed parameters within the category. The “Evaluation test” column describes test conditions for exploring the tradeoff space of a category.

The tests completed during the Phase II work described in this document began to address certain of these test areas, such as evaluation of the MIMO versus SISO antenna configuration comparison. This list of test and evaluation areas is available for consideration when designing future tests.

TABLE 13.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
Base station (BS)	Mounting placement	Analyze or simulate Verify analysis or simulation model Survey signal strength across airport surface Determine line of sight (LOS) and non line of sight (NLOS)
	Number of BSs and base transceiver station (BTS) sectors	Analyze, considering coverage area and composite throughput
	Multiple input, multiple output (MIMO) order	Test without MIMO Test with up to 2×2 MIMO Test with *N*×*N* MIMO Test with LOS and with NLOS or blockage
	Antenna polarization	Evaluate internal cross-polarization antennas versus external spatially separated antennas
	Maximum cell range	Extend with Media Access Control (MAC) changes within Institute of Electrical and Electronics Engineering (IEEE) 802.16e specification Evaluate IEEE 802.16m amendment
	Controlled-pattern antennas	Test with advanced BTS sector antennas Identify and evaluate steerable multi-beam antennas
	Frequency band	Analyze minimum spectrum versus needed throughput
	Spectrum co-user interference (i.e., Globalstar satellite)	Analyze
Subscriber station (SS)	Mounting height	Analyze
	MIMO order	Test without MIMO Test with up to 2×2 MIMO Test with *N*×*N* MIMO
	Antenna polarization	Evaluate internal cross-polarization antennas versus two external single-polarization antennas
	Maximum cell range	Extend with MAC changes within IEEE 802.16e specification Evaluate IEEE 802.16m amendment
	Frequency band	Analyze minimum spectrum versus needed throughput Test frequency reuse methods including $N = 1$ (all sectors on same center frequency)
	Spectrum co-user interference (i.e., Globalstar satellite)	Analyze on the basis of power class requirements and frequency reuse method
Channel bandwidth	Throughput rate	Test mixed mobile SS and fixed SS traffic including • Sources of highest expected data rate • Channel bandwidths of 5, 10, and 20 MHz
	Mobility performance	Test mobility throughput over speed range and cell radius including • Multiple mobile SS • Channel bandwidths of 5, 10, and 20 MHz
	Multipath performance	Evaluate performance in terminal area Evaluate mobile performance in building areas
	Efficient use of spectrum	Evaluate multiple mobile SS operation concurrent with fixed SS of differing data streams
	Hardware limitations	Test throughput versus expected at 20-MHz bandwidth
Modulation	Adaptive or fixed	Measure mobility throughput measurements across cell radius with fixed high and low modulation rates

TABLE 13.—EXPERIMENTS AND TEST PLAN TRADEOFF SPACE

Design tradeoff category	Parameters	Evaluation test
	Modulation rates	Compare measured versus expected throughput versus modulation coding rate, including • Ranges from cell center to cell edge • LOS and NLOS
	Forward error correction (FEC) coding rate	Compare measured versus expected throughput versus error coding rate, including • Ranges from cell center to cell edge • LOS and NLOS
BTS power class	Fade margin allowance	Test long-term LOS throughput Conduct mobility tests in NLOS and high-multipath conditions
	Co-channel interference	Test throughput versus power between isolated sectors at the same center frequency in a frequency-reuse system
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Analyze interference on the basis of minimum power required to provide coverage across airport surface
	Range	Determine cell radius versus number of BSs
	Power amplifier power-output limitations	Analyze
SS power class	Fade margin allowance	Test long-term LOS throughput Conduct mobility tests in NLOS and high-multipath conditions
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Analyze interference on the basis of minimum power required to provide coverage across the airport surface
	Range	Determine cell radius versus the number of BSs
	Power amplifier power-output limitations	Analyze
MAC layer and physical layer (PHY)	Maximum mobile speed	Conduct high-speed mobility tests for throughput and dropouts
	Repeater operation (IEEE 802.16j)	Test IEEE-802.16j-enabled BS when available for filling in poor coverage areas, including • Outside cell radius • NLOS regions
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	Analyze
Quality of service (QoS)	Time delay	Measure end-to-end time delay through AeroMACS network from SS input through CSN output port for all five QoS levels
	Time jitter	Measure end-to-end time jitter through AeroMACS network from SS input through CSN output port for all five QoS levels
	Message priority	Test high QoS and best-effort traffic Test until throughput overload Verify that high QoS priority is maintained
	Scheduling	Test high QoS and best-effort traffic Measure statistics of scheduling accuracy Measure scheduling performance as throughput is increased to overload
	Message integrity	Test high QoS and best-effort traffic Test continuous and burst traffic Verify packet error rate and that there are no dropped packets for high QoS traffic

4.0 Initial Input to Aeronautical Mobile Specific IEEE 802.16 Design Specification

The IEEE 802.16 standard (Ref. 8) defines system profiles that list sets of features that apply to particular implementation cases. The IEEE 802.16e amendment (Ref. 9) adding mobility also amended the system profile. For this reason, the IEEE 802.16 standard and the IEEE 802.16e amendment must be used together to create the AeroMACS profile. In this report, the IEEE 802.16 standard plus the IEEE 802.16e amendment are referred to as IEEE 802.16–2009, the updated standard that incorporates both. Section 4.0 was written prior to the release of the IEEE 802.16–2009 updated standard and references paragraphs and tables from the earlier IEEE 802.16e–2005 document.

4.1 AeroMACS Standard Profile

The IEEE 802.16 profiles to be evaluated here are limited in scope to functions of the MAC and PHY reference model layers. In addition, profiles defined by the WiMAX Forum include parameters from higher-level reference layers. These added parameters define support for network and security functions, for example.

The AeroMACS profile will use the same conventions for “mandatory” and “optional” features as defined by the WiMAX Forum for commercial system profiles. These descriptors are selected to define AeroMACS PHY and MAC operation within the bounds set by the standard.

Four system profiles are used to define sets of features that are a subset of IEEE 802.16 according to these four classes:

(1) Wireless municipal area network, single carrier (WirelessMAN-SC, 10 to 66 GHz)
(2) WirelessMAN and wireless high-speed unlicensed metropolitan area networks, single-carrier access (WirelessMAN-SCa and WirelessHUMAN-SCa)
(3) WirelessMAN and WirelessHUMAN, OFDM (WirelessMAN-OFDM and WirelessHUMAN-OFDM)
(4) WirelessMAN and WirelessHUMAN, OFDMA (WirelessMAN-OFDMA and WirelessHUMAN-OFDMA)

Table 14 examines the suitability of these four system profile feature sets for AeroMACS.

TABLE 14.—IEEE 802.16 STANDARD PROFILE FEATURE SETS

Profile set	Evaluation as basis for AeroMACS profile
1. WirelessMAN-SC (10 to 66 GHz)	Incorrect frequency range for AeroMACS operating in C-band
2. WirelessMAN-SCa and WirelessHUMAN-SCa	Lacks the support for mobility needed for AeroMACS
3. WirelessMAN-OFDM and WirelessHUMAN-OFDM	Lacks support for the mobility needed for AeroMACS (This is the profile for “Fixed WiMAX™”.)
4. WirelessMAN-OFDMA and WirelessHUMAN-OFDMA	Correct profile to use as basis for an AeroMACS profile; supports C-band, mobility, and multiple-use access

The WirelessMAN-OFDMA and WirelessHUMAN-OFDMA (profile 4) defines a wireless system with support for mobility. These are the feature sets used by the WiMAX Forum to define mobile WiMAX wireless service profiles and will be the basis for an AeroMACS profile. This not only provides the desired mobility performance, it allows equipment vendors to adapt commercially available off-the shelf hardware with minimum modifications.

Note that in IEEE 802.16e, the WirelessMAN and WirelessHUMAN specification classes are contained in a common profile set. These specification classes are separated into separate profile sets in the IEEE 802.16–2009 standard. This report remains consistent as an analysis of the IEEE 802.16e standard and uses its format.

4.1.1 System Profile Definition Method

The process for developing specification-level profile recommendations follows:

(1) Begin with system profiles defined in the IEEE 802.16–2004 standard and the IEEE 802.16e–2005 amendment.
(2) Identify parameters in the system profile that must change to support C-band AeroMACS operation. The center frequency definition is an example.
(3) Compare the resulting C-band system profile to requirements flowed down from ConUse and system studies, and identify areas that are not supported, if any.
(4) Recommend additional changes to the system profile or recommend areas for further research into parameters that will better meet requirements while examining the cost of requiring additional hardware changes.

4.1.2 System Profile Definitions

This subsection defines recommended profiles for systems operating with AeroMACS air interfaces. Any feature not mandatory or conditionally mandatory for a profile is optional for the profile except where otherwise forbidden by the IEEE 802.16(e) standard. Optional features shall be implemented as specified in the standard. Design consideration comments are provided in each subsection to provide guidance for operation within the ranges of parameters that are offered within the profiles.

Table 15 defines four profiles for AeroMACS. AeroMACS_profM1 applies to all channel bandwidths. AeroMACS_profP1 to AeroMACS_profP3 apply to specific channel bandwidths.

TABLE 15.—AeroMACS PROFILE DEFINITIONS

Identifier	Description
AeroMACS_profM1	Basic packet point-to-multipoint Media Access Control (MAC) profile
AeroMACS_profP1	Basic physical layer (PHY) profile for 5-MHz channel
AeroMACS_profP2	Basic PHY profile for 10-MHz channel
AeroMACS_profP3	Basic PHY profile for 20-MHz channel

Note that 5-MHz channels are not included in the IEEE 802.16(e) standard but are included in the WiMAX Forum profile. These channels are incorporated in the AeroMACS standard recommendation because the 5-MHz channel is the lowest multiple of the center frequency f_c step and because it provides for more efficient use of the AeroMACS spectrum than wider channel bandwidths do. In addition, the 5-MHz center frequency f_c step size was chosen to be consistent with the IEEE 802.16e standard for 5000-MHz unlicensed bands. This will facilitate hardware reuse by vendors.

Although 5-MHz channel bandwidths will limit PHY and MAC performance in mobile and high-multipath environments and will limit the maximum data throughput available to each subscriber, larger channel bandwidths would impair a system designer’s ability to efficiently use the 5091- to 5150-MHz approved spectrum and the potential 5000- to 5030-MHz expansion band.

4.1.3 AeroMACS Power Class Profiles

The power class profiles recommended for AeroMACS correspond with those stated in Section 12.4.1 of the IEEE 802.16 standard. A power class profile contains the classes of SSs (fixed-position and mobile) used in a system. A power class profile may contain transmitters from more than one class, with the profile indicating the highest power class permitted. The recommended power classes are listed in Table 16.

TABLE 16.—AeroMACS POWER CLASSES

Class	Transmit power, dBm
1	$17 \leq P_{Tx,\,\mathrm{max}} < 20$
2	$20 \leq P_{Tx,\,\mathrm{max}} < 23$
3	$23 \leq P_{Tx,\,\mathrm{max}} < 30$
4	$30 \leq P_{Tx,\,\mathrm{max}}$

The power ratings $P_{Tx,\,\mathrm{max}}$ associated with these classes are the maximum average output power ratings at which the appropriate transmitter requirements in Section 8.4.12 of IEEE 802.16(e) are met.

Network system designers should use the following design considerations to minimize AeroMACS inference with coexisting in-band services:

- For mobile SSs, select the number of BSs and their placement to enable low power class operation of MSs within their roaming area.
- For fixed-site SSs, specify the use of high-directivity, high-gain fixed-site antennas to minimize the SS power class.
- Use diversity propagation MIMO antenna systems for increased sensitivity with lower power class operation.

4.1.4 AeroMACS Media Access Control Profiles

The OFDMA_ProfM1 profile in Section 12.4.2 of the IEEE 802.16(e) standard is recommended for use in AeroMACS without modification. This MAC profile specifies mobile operation for WirelessMAN-OFDMA and WirelessHUMAN-OFDMA air interfaces. In particular

- Using the OFDMA_ProfM1 profile without modification maximizes the reuse of commercial off-the-shelf hardware available for nearby licensed bands. Reuse of the profile gives system designers the flexibility to tailor performance for the airport environment with the parameter options that are available.
- MAC parameters provide for mobile operation. The maximum speed supported in commercial mobile WiMAX is generally on the order of 120 km/hr. However, the actual maximum speed depends on many factors, including the frequency of operation. Greater maximum speeds are possible with changes in MAC parameters at the expense of performance in other areas such as data throughput. Future studies regarding adjustments to MAC parameters are needed to accommodate increased mobility speeds. Studies must include a cost/benefit analysis to weigh changes in other performance parameters against the benefit of operation at increased operating speed.
- The IEEE 802.16m amendment planned for future release will include MAC modifications that will increase the maximum operating speed above that of IEEE 802.16–2009.

4.1.5 AeroMACS Network Physical Layer Profiles

This subsection defines PHY profiles for systems operating with the AeroMACS air interfaces. We recommend that IEEE 802.16(e) PHY profiles be used without modification for all features except for FDD PHYs. FDD transmissions require the use of two separate channels; one for UL and the other for

DL. These channels require adequate frequency separation so that the transmitter does not desensitize the receiver, which needs to operate simultaneously. Practical FDD systems separate transmit and receive channels by at least 3 percent (Ref. 10), which exceeds the C-band AM(R)S allocation of 59 MHz.

The following PHY profile definitions define the minimum performance required for each channel bandwidth. These requirements are in addition to the minimum performance requirements needed for all profiles, as defined in Table 413 of the IEEE 802.16(e) specification.

4.1.6 Basic Physical Layer (PHY) Profile for the AeroMACS 5-MHz Channel

A system implementing the AeroMACS_profP1 shall meet the minimum performance requirements listed in Table 17 (derived from the IEEE 802.16(e) specification).

TABLE 17.—BASIC PHY PROFILE FOR AeroMACS 5-MHZ CHANNEL
[Acronyms are defined in Appendix A]

Capability	Minimum performance
Channel bandwidth, MHz	5
Operation mode	Licensed AM(R)S C-band operation
Bit error rate (BER) performance threshold (BER = 10^{-6} if using all subchannels BS/SS)[a]	Greater than or equal to
QPSK 1/2, dBm	–85
QPSK 3/4, dBm	–82
16–QAM 1/2, dBm	–78
16–QAM 3/4, dBm	–75
64–QAM 2/3 (if 64–QAM supported), dBm	–71
64–QAM 3/4 (if 64–QAM supported), dBm	–69
Reference frequency tolerance	
BS	$\leq \pm 2\times10^{-6}$
SS to BS synchronization tolerance, Hz	≤22.5
Frame duration code set[b]	{2, 4, 5}

[a]Add to sensitivity $10\times\log^{10}$ (number of subchannels in the BS receiver).
[b]See Table 232 of the IEEE 802.16(e) standard (Ref. 9).

4.1.7 Basic Physical Layer (PHY) Profile for AeroMACS 10-MHz Channel

A system implementing AeroMACS_profP2 shall meet the minimum performance requirements listed in Table 18 (derived from the IEEE 802.16(e) specification).

TABLE 18.—BASIC PHY PROFILE FOR AeroMACS 10-MHZ CHANNEL
[Acronyms are defined in Appendix A.]

Capability	Minimum performance
Channel bandwidth, MHz	10
Operation mode	Licensed AM(R)S C-band operation
Bit error rate (BER) performance threshold (BER = 10^{-6} if using all subchannels BS/SS)[a]	Greater than or equal to
QPSK 1/2, dBm	–82
QPSK 3/4, dBm	–79
16–QAM 1/2, dBm	–75
16–QAM 3/4, dBm	–72
64–QAM 2/3 (if 64–QAM supported), dBm	–68
64–QAM 3/4 (if 64–QAM supported), dBm	–66
Reference frequency tolerance	
BS	$\leq \pm 2\times10^{-6}$
SS to BS synchronization tolerance, Hz	≤55
Frame duration code set[b]	{2, 4, 5}

[a]Add to sensitivity $10\times\log^{10}$ (number of subchannels in the BS receiver).
[b]See Table 232 of the IEEE 802.16(e) standard (Ref. 6).

4.1.8 Basic Physical Layer (PHY) Profile for AeroMACS 20-MHz Channel

A system implementing AeroMACS_profP3 shall meet the minimum performance requirements listed in Table 19 (derived from the IEEE 802.16(e) specification).

TABLE 19.—BASIC PHY PROFILE FOR AeroMACS 20-MHZ CHANNEL
[Acronyms are defined in Appendix A.]

Capability	Minimum performance
Channel bandwidth, MHz	20
Operation mode	Licensed AM(R)S C-band operation
Bit error rate (BER) performance threshold (BER = 10^{-6} if using all subchannels BS/SS)[a]	Greater than or equal to
QPSK 1/2, dBm	–79
QPSK 3/4, dBm	–76
16–QAM 1/2, dBm	–72
16–QAM 3/4, dBm	–69
64–QAM 2/3 (if 64–QAM supported), dBm	–65
64–QAM 3/4 (if 64–QAM supported), dBm	–63
Reference frequency tolerance	
BS	$\leq \pm 2\times10^{-6}$
SS to BS synchronization tolerance, Hz	≤ 110
Frame duration code set[b]	{2, 4, 5}

[a]Add to sensitivity $10\times\log^{10}$ (number of subchannels in the BS receiver).
[b]See Table 232 of the IEEE 802.16(e) standard (Ref. 6).

4.1.9 AeroMACS Radiofrequency Profiles

This subsection defines proposed RF profiles for the AeroMACS air interfaces. Table 20 defines the RF channels for informative purposes. The channels shall be calculated using the following equation:

$$F_{\text{start}} + n \bullet \Delta f_c \text{ for all } n \text{ in } N_{\text{range}}$$

where

F_{start} start frequency for the specified band
Δf_c center frequency step
N_{range} range of values for the n parameter

TABLE 20.—RADIOFREQUENCY PROFILE LIST FOR AeroMACS C-BAND

Radiofrequency profile	Channel bandwidth, MHz	Center frequency step,[a] Δf_c, MHz	Uplink (UL) start frequency, F_{start}, MHz	Downlink (DL) start frequency,[b] F_{start}, MHz	Range of values for n, N_{range}
AeroMACS_ProfR1	5	5	5000	N/A	{19, 20, …, 37}
AeroMACS_ProfR2	10	5	5000	N/A	{20, 21, …, 36}
AeroMACS_ProfR3	20	5	5000	N/A	{21, 22, …, 35}
AeroMACS_ProfR4[c]	5	5	5000	N/A	{1, 2, …, 5}
AeroMACS_ProfR5[c]	10	5	5000	N/A	{1, 3, …, 5}
AeroMACS_ProfR6[c]	20	5	5000	N/A	{2, 3, … 4}

[a]The minimum center frequency step Δf_c is 5 MHz to match the IEEE 802.16(e) standard for the 5000-MHz frequency bands. The center frequency step Δf_c of 5 MHz requires that the minimum channel bandwidth be 5 MHz and that channel bandwidths increase in multiples of 5 MHz.
[b]DL F_{start} = UL F_{start} in a TDD system.
[c]Use of a profile is dependent on International Telecommunications Union (ITU) authorization.

5.0 Final Requirements and Specifications Recommendations for the C-Band System

5.1 Final Performance Requirements Recommendations

Table 21 relates AeroMACS technical parameters, requirement source for each parameter, and the profile parameter area that is directly impacted. When a technical parameter is indicated as only impacting airport system design, the parameter will be finalized during the system design process for a new airport installation. For example, the number of BTS sectors to be used at a specific airport will be determined in the system design process using the range of settings that are available within the AeroMACS profile parameters.

Sections 5.1 and 5.2 were written during the Phase I of Task 7 prior to the release of the IEEE 802.16–2009 updated standard. Although these sections reference paragraphs and tables from the earlier IEEE 802.16e–2005 document, the information is still pertinent.

TABLE 21.—AeroMACS C-BAND RADIOFREQUENCY PROFILE LIST

Design tradeoff category	Technical parameters	Affected process					
		IEEE 802.16e profile parameter area					
		Airport system design	Radio-frequency/ radio	Power class	Duplex mode	Physical (PHY) design	Media Access Control (MAC) design
Base station	Placement/location/ height	x					
	Number of base transceiver station (BTS) sectors	x					
	Multiple input, multiple output (MIMO) order	x	x	x		x	x
	Antenna polarization	x					
	Maximum cell range	x					x
	Controlled-pattern antennas	x					x
	Frequency band	x	x		x		
	Spectrum co-user interference (i.e., Globalstar satellite)	x					
Subscriber station	Mounting height	x					
	MIMO order	x				x	x
	Antenna polarization	x					
	Maximum cell range	x					x
	Frequency band		x		x		
	Spectrum co-user interference (i.e., Globalstar satellite)	x					

TABLE 21.—AeroMACS C-BAND RADIOFREQUENCY PROFILE LIST

Design tradeoff category	Technical parameters	Affected process					
		IEEE 802.16e profile parameter area					
		Airport system design	Radio-frequency/ radio	Power class	Duplex mode	Physical (PHY) design	Media Access Control (MAC) design
Channel bandwidth	Throughput rate	x					x
	Mobility performance	x					x
	Multipath performance	x					
	Efficient use of spectrum	x					
	Co-channel interference	x					
	Hardware limitations					x	
Modulation	Adaptive or fixed	x				x	
	Modulation rates	x				x	
	Forward error-correction (FEC) coding rate	x				x	
BTS power class	Fade margin	x					
	Co-channel interference	x					
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	x		x			
	Range	x					
	Line-of-sight (LOS) and non-line-of-sight (NLOS) operation	x				x	
	Mobile operation	x				x	
	Power amplifier power-output limitations			x		x	
SS power class	Fade margin	x					
	Co-channel interference	x					
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	x		x			
	Range	x					
	LOS and NLOS operation	x					
	Mobile operation	x					
	Power amplifier power-output limitations			x		x	

TABLE 21.—AeroMACS C-BAND RADIOFREQUENCY PROFILE LIST

Design tradeoff category	Technical parameters	Affected process					
		IEEE 802.16e profile parameter area					
		Airport system design	Radio-frequency/ radio	Power class	Duplex mode	Physical (PHY) design	Media Access Control (MAC) design
(MAC and PHY layers	Maximum mobile speed						x
	Repeater operation (IEEE 802.16j)	x					x
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode				x		
Quality of service (QoS)	Time delay	x			x		x
	Time jitter	x	x		x	x	x
	Message priority						x
	Scheduling						
	Message integrity	x	x	x		x	x

However, the number of BSs is not an AeroMACS profile parameter because it will be highly dependent on airport geographic size and the assessment of total data throughput for the network. Other parameters, such as frequency band, do impact the AeroMACS profile parameter area in the areas of RF radio design and duplex mode.

The PHY and MAC designs will accommodate the system design space to a degree with the range of parameter settings that are within the profile. If an application requires a level of performance that cannot be met with PHY and MAC parameters within the profile, a redesign will need to occur that will move the AeroMACS hardware further away from being a simple modification to a commercial off-the-shelf WiMAX. For example, requiring greater mobile speeds than can be provided with commercial off-the-shelf WiMAX hardware will require a redesign of the PHY and MAC layers.

5.2 Final Input to Aviation-Specific IEEE 802.16 System Design Specifications

Table 22 summarizes the key parameter selections that are recommended for an AeroMACS standard profile. The five profile areas listed in Table 22 correspond with the five profile areas that distinguish mobile WiMAX profiles.

TABLE 22.—SUMMARY OF FINAL RECOMMENDATIONS FOR AeroMACS PROFILE

Profile area	Key parameter selections
Radiofrequency and radio parameters	
Frequency band, MHz	5091 to 5150
Channel bandwidths, MHz	5, 10, and 20
Channel center frequencies	See Table 20
Power class	
Maximum downlink transmitter (Tx) power	Section 4.1.3—Unchanged from IEEE 802.16(e)
Maximum uplink Tx power	Section 4.1.3—Unchanged from IEEE 802.16(e)
Duplex mode (time-division duplex (TDD) or frequency-division duplex (FDD))	TDD
Physical layer M-ary quadrature amplitude modulation (QAM) range Coding options Multiple input, multiple output (MIMO)	Performance profiles—minimum performance defined in IEEE 802.16(e) and Table 17 for 5-MHz channels Table 18 for 10-MHz channels Table 19 for 20-MHz channels
Media Access Control (MAC) layer Automatic repeat request Security protocols Mobile protocols Quality-of-service (QoS) options Mesh options	All parameters unchanged from IEEE 802.16(e)

5.2.1 Draft RTCA AeroMACS Profile

Special Committee SC–223 was established within the RTCA aviation industry consortium to establish standards for AeroMACS. The principal products of this special committee are a set of system profile recommendations delivered in September 2010 and a minimum operational performance standards (MOPS) document to be delivered in December 2011 (Ref. 2). The European Organisation for Civil Aviation Equipment (EUROCAE) established a parallel work group, WG–82, that is chartered to develop an AeroMACS profile for use in Europe that is interoperable with the AeroMACS profile developed by RTCA. SC–223 and WG–82 are working cooperatively to develop a common profile document that will be provided as recommendations for consideration by ICAO.

5.2.2 WiMAX Forum AeroMACS Ad-Hoc Working Group

A technical parameter profile has been developed for AeroMACS that is patterned after the WiMAX Forum Mobile System Profile Specification developed for commercial mobile WiMAX systems. The AeroMACS profile is based on the WiMAX Forum Mobile System Profile: Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02) document[8] that was developed and is maintained by the WiMAX Forum. A joint RTCA and WiMAX Forum ad hoc working group has been established to develop an AeroMACS profile that is consistent with WiMAX Forum documentation and processes.

An AeroMACS profile ensures that all stakeholders—test equipment vendors, integrated circuit vendors, as well as the aviation industry—are capable of supporting the AeroMACS development and

[8]Available at http://www.wimaxforum.org/resources/documents/technical/T24

that a deployment will be globally inter-operable. A profile will be used as a guide for development of a Minimum Operating Standards (MOPS) document within RTCA SC–223.

WiMAX Forum profiles are referenced in the IEEE 802.16–2009 standard in three main parts: COMMON, TDD, and FDD.

The recommended AeroMACS is a TDD-only system so the third part of the WiMAX Forum profile will not be used. AeroMACS will be based on Release 1.0 profile because it is presently the only release certified by the WiMAX Forum for use by industry. Release 1.5 has been approved but not implemented for hardware certification because the IEEE 802.16m amendment is expected to be implemented soon with profile Release 2.0. The RTCA SC–223 and EUROCAE WG-82 decided jointly not to implement features of profile Release 2.0 at this time because that release of the WiMAX standard is still in development.

5.2.3 Draft RTCA AeroMACS Profile Status

An AeroMACS profile has been developed through a series of RTCA and EUROCAE meetings and telephone conferences, often with WiMAX Forum participation. SC–223 and WG-82 leadership participated in all plenary meetings of each other’s organizations. An ad-hoc joint committee was established between RTCA SC–223 and the WiMAX Forum in August 2010. A joint RTCA and EUROCAE meeting was held in Brussels, Belgium in late October 2010, with participation by members of the WiMAX Forum via telephone conference in which many profile parameter settings were established for AeroMACS. A fully harmonized profile was established during the RTCA SC–223 Plenary Meeting #8 in November 2010. This harmonized profile is available on the RTCA SC–223 Workspace site[9]. The profile document is based on the WiMAX Forum Release 1.0 profile and includes a rationale statement for the setting chosen for each parameter.

The joint AeroMACS profile completed in December 2010 is the RTCA “final draft” version. EUROCAE will continue their studies in 2011, leading to a “final joint profile” by the end of 2011 that may differ from the 2010 final draft profile based on results of the EUROCAE studies. EUROCAE plans to complete validation tests before publishing a final AeroMACS profile by the end of 2013.

[9] Available at http://workspace.rtca.org/kws/my_account Access permission is required.

Appendix A.—Acronyms and Abbreviations

This appendix identifies acronyms and abbreviations used throughout this document.

A/A	air to air
A/C	aircraft
A/G	air to ground
AAA	authentication, authorization, and accounting
ACARS	Aircraft Communications Addressing and Reporting System
ACSTS	Aerospace Communication Systems Technical Support contract
ADAS	AWOS Data Acquisition System
ADDS	Aviation Digital Data Service
ADS–B	automatic dependent surveillance—broadcast
ADS–C	automatic dependent surveillance—contract
ADSx	automatic dependent surveillance—next generation
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Aircraft Communications System
AFB	Air Force base
AFSS	Automated Flight Service Station
AIM	Aeronautical Information Management
AISR	Aeronautical Information System Replacement
ALS	airport lighting system
ALSF	approach lighting with sequenced flashing lights
AM(R)S	aeronautical mobile (route) service
AMS(R)S	aeronautical mobile satellite (route) service
ANSP	air navigation service provider
AOC	aeronautical operational control
AP–17, –30	Action Plan 17, 30
ARCTR	aeronautical center in Oklahoma City, Oklahoma
ARFF	Aircraft Rescue and Firefighting building (at Cleveland Hopkins International Airport)
ARINC	Aeronautical Radio Incorporated
ARSR	air route surveillance radar

ARTCC	air route traffic control center
ARTS	Automated Radar Terminal System
ARV	Aeronautical Research Vehicle
ASOS	automated surface observation systems
ASR	airport surveillance radar
ATC	air traffic control
ATCSCC	air traffic control system command center
ATCT	air traffic control tower
ATFCM	air traffic flow and capacity management
ATIS	Automatic Terminal Information Service
ATM	air traffic management
ATN	aeronautical telecommunications network
ATO	Air Traffic Organization
ATS	air traffic services
ATSP	air traffic service provider
ATSU	air traffic services unit
AWIPS	Advanced Weather Interactive Processing System
AWOS	Automated Weather Observing System
AZ	azimuth
BE	best effort
BER	bit error rate
BLOS	beyond line of sight
BS	base station
BTS	base transceiver station
CDM	collaborative decision making
CLE	Cleveland Hopkins International Airport, Cleveland, Ohio
CMF	Consolidated Maintenance Facility
CNS	communication, navigation, and surveillance
COCR	communications operating concept and requirements
COM	communications
ConOps	concepts of operation
ConUse	concepts of use
CP	cyclic prefix

CPDLC	controller pilot data link communications
CPE	customer premise equipment (same as subscriber station)
CSN	Connectivity Service Network
CTA	Controlled Time of Arrival
D/L	data link
Data Comm	Data Communications Program
dATIS (D–ATIS)	Digital Automatic Terminal Information Service
DC	data communications
DCG	data communications gateway
DCS	data communications system
DHS	Department of Homeland Security
DINS	Defense Internet NOTAM (Notice to Airmen) services
DL	downlink—base station to subscriber station data-flow direction
DME	distance measuring equipment
DoD	Department of Defense
D–OTIS	data link operational terminal information service
D–RVR	data link runway visual range
D–SIG	data link surface information and guidance
D–SIGMET	data link significant meteorological information
DSS	decision support system
D–TAXI (D-Taxi)	data link taxi clearance
DTS	Dedicated Telecom Services
DYNAV	dynamic route availability
EA	enterprise architecture
EAR	Export Administrative Regulations
ECS	emergency communications systems
EUR	Europe
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
F&F	flight and flow
FAA	Federal Aviation Administration
FCI	future communications infrastructure
FCS	Future Communications Study

FDD	frequency-division duplex
FEC	forward error correction
FFT	fast Fourier transform
FLIPCY	flight plan consistency
FMS	flight management system
FOC	Flight Operations Center
FPR	Final Program Requirements
FRS	future radio system
FTP	File Transfer Protocol
FY	fiscal year
G/A	general aviation
G/G	ground to ground
GA	general aviation
GBT	ground-based transceiver
GI	general information
GIS	geographical information system
GPS	Global Positioning System
GS	ground station
HF	high frequency
ICAO	International Civil Aviation Organization
ID	identification
IDS	Information Display System
IDU	indoor unit
IEEE	Institute of Electrical and Electronics Engineering
ILS	instrument landing system
IP	Internet Protocol
Iperf	network testing tool
ITP	In-Trail Procedure
ITU	International Telecommunications Union
ITWS	Integrated Terminal Weather System
JPDO	Joint Planning and Development Office
LINK 2K+	European SESAR (Single European Sky ATM Research) program
Loc	location

LOS	line of sight
M&S	merging and spacing
MAC	Media Access Control
M-ary	digital transmission of two or more bits at a time
MIMO	multiple input, multiple output
MLAT	multilateration
MM	middle marker
Mode S	Mode Select secondary surveillance Beacon System
MOPS	Minimum Operational Performance Standards
MS	mobile station
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASA–CLE	NASA Glenn Research Center and Cleveland Hopkins International Airport
NASA Glenn	NASA Glenn Research Center
NAS–SR	National Airspace System—System Requirements
NAV	navigation
NAVAIDS	navigation aids
NDB	nondirectional radio beacon
NE	northeast
NEXCOM	Next Generation Air/Ground Communications
NEXRAD	Next Generation Radar
NextGen	Next Generation Air Transportation System
NLOS	non line of sight
NMS	Network Management System
NNCC	National Network Control Centers
NNEW	NextGen Network Enabled Weather
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
nRT	non real time
nrtPS	non-real-time polling service
NWS	National Weather Service
ODU	outdoor unit

OFDM	orthogonal-frequency-division multiplexing
OFDMA	orthogonal-frequency-division multiple access
OI	operational improvement
OM	outer marker
Ops IP	operations IP
Ops	operations
ORIS	operational en route information service
OSED	Operational Services and Environment Definition
OTIS	operational terminal information service
OV–1, OV–2	operational views
PC	personal computer
PER	packet error rate
PHY	physical
PIREP	pilot report
PLA	project-level agreement
PoE	Power over Ethernet
PPD	pilot preferences downlink
PSN	packet switched network
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase-shift keying
RCE	radio control equipment
RCE–C	RCE at control site
RCE–R	RCE at remote (transmitter/receiver) site
RCO	remote communication outlet
RCP	required communication performance
RF	radiofrequency
RRM	radio resource management
RSSI	received signal strength indication
RTCA	RTCA, Inc. (founded as Radio Technical Commission for Aeronautics)
rtPS	real-time polling service
RTR	remote transmitter/receiver
RUC	rapid update cycle

RVR	runway visual range
Rx	receiver
SAMS	Special Use Airspace Management System
SARPs	standards and recommended practices
SATCOM	satellite communications
SC	single carrier; special committee
SE	system engineering
SEM	system engineering manual
SESAR	Single European Sky ATM Research
SIGMET	significant meteorological information
SOC	Service Operations Center
SOCC	Security Operations Control Center
SPR	safety and performance requirement
SR	system requirement
SRD	system requirements document
SRR	short-range radar
SS	subscriber station
SSR	secondary surveillance radar
surv	surveillance
SV–1, SV–2	system views
SW	southwest
SWIM	System Wide Information Management
SYSCO	system-supported coordination
TACAN	tactical air navigation
TAP/CDA	Tailored Arrival Procedure/Continuous Descent Approach (Arrival)
TBO	trajectory-based operations
TCP	transmission control protocol
TDD	time-division duplex
TDLS	tower data link system
TDMA	time-division multiple access
TFM	traffic flow management
TFR	temporary flight restrictions
TM	Traffic Management

TMA	terminal maneuvering area
TVS	Terminal Voice Switch
Tx	transmitter
UAT	universal access transceiver
UDP	User Datagram Protocol
UGS	unsolicited grant service
UHF	ultra-high frequency
UL	uplink—subscriber station to base station data-flow direction
URCO	urgent contact
VCS	Voice Communications System
VDL	very high frequency digital link
VHF	very high frequency
VLAN	virtual local area network
VoIP	digital voice over Internet Protocol
VOR	very high frequency (VHF) omnidirectional range
VPN	virtual private network
WAKE	wake vortex
WARC	World Administrative Radio Conference (now World Radiocommunication Conference)
WARP	Weather and Radar Processor
WiMAX	Worldwide Interoperability Microwave Access
WINS	Weather Information Network Server
WirelessHUMAN	wireless high-speed unlicensed municipal area network
WirelessMAN	wireless municipal area network
WRC	World Radiocommunication Conference
Wx	weather
4–D	four dimensional (latitude, longitude, altitude, and time)
4DLINK	proposal for the next data link package that targets initial four-dimensional trajectories and airport services (This capability fits in Implementation Package 2 as identified by the Single European Sky ATM Research (SESAR) Master Plan.)
4DT	four-dimensional trajectory (latitude, longitude, altitude, and time)

Appendix B.—Task 7-1 Phase II, NASA-Cleveland AeroMACS Test Bed Test Plan

B.1 Test Case 1, Multilateration (MLAT) Communications

B.1.1 Purpose of Tests

A series of tests will measure the network performance of an AeroMACS network for communication of multilateration (MLAT) sensor data traffic. End-to-end network performance will be evaluated using live connections to MLAT sensor stations in the NASA–CLE Test Bed. Communications will be evaluated between up to eight MLAT sensor sites on the airport surface and the MLAT processor located in NASA B110, Room 310.

AeroMACS traffic will include a mixture of live MLAT sensor feed and test data streams generated by IxChariot software. Test traffic will be added to the network to evaluate the effects on throughput capacity, packet integrity, and time latency caused by network congestion and by mixing types of traffic.

B.1.2 AeroMACS Network Configuration

B.1.2.1 Physical Configuration

The network is to be operational with two multisector base stations (BSs), eight subscriber stations (SSs), and an operating core network that includes backhaul links to a secure router and servers with authentication, authorization, and accounting (AAA) and Network Management Server (NMS) applications. The equipment that is available for this test case is listed in Section B.7.

Ethernet internet protocol (IP) connectivity will be established between MLAT sensor equipment and an AeroMACS SS at each of eight MLAT sites on the Cleveland Hopkins (CLE) airport surface. The Ethernet connection will be established between network switches in both systems. MLAT traffic will be carried from the Sensis equipment to the AeroMACS core on dedicated virtual local area network (VLAN) 30.

B.1.2.2 Air Link and Network Configuration

The AeroMACS network will be configured according to the settings of Table 23 using Alepo AAA and Alvaristar NMS.

TABLE 23.—TEST CASE 1 AIR LINK AND NETWORK CONFIGURATION SETTINGS
[Acronyms are defined in Appendix A.]

AeroMACS parameter		Setting
AAA server		Enabled
PKMv2, EAP-TTLS security		Enabled
AES-128 air link encryption		Enabled
Maximum transmission unit (MTU) size		1440 bytes
DL/UL ratio		60/40
HARQ		Enabled
MIMO		Mode A
Channel bandwidth		5 MHz
Quality of service (QoS)		Set per test plan
BTS center frequencies, MHz		
	BTS1-1	5095
	BTS1-2	5145
	BTS2-1	5135
	BTS2-2	5115
	BTS2-3	5100
BTS Tx power, dBm		
	BTS1-1	15
	BTS1-2	15
	BTS2-1	20
	BTS2-2	20
	BTS2-3	24
SS UL RSSI, dBm		–50 to –75
SS UL CINR		> 14 dB
SS DL RSSI, dBm		–50 to–75
SS DL CINR		> 14 dBi
BTS firmware version		4.6.2.2/24848
SS firmware version		1.5.1.16
Alepo AAA version		7.2
Alvaristar NMS version		4.5.0.47.Patch
Device driver version		1.5.0.31.beta

B.1.3 Test Procedure

B.1.3.1 AeroMACS Configuration

With AeroMACS configured according to Section 1.2 and no added test traffic, verify that live sensor data traffic feeds are transported to the secure router VLAN 30 port for each of the eight MLAT sensor sites. Perform the following:

a. Stop all sources of traffic that are not related to this test by closing ports on managed switches at the SS sites.
b. Survey connectivity to determine which SSs are connected to which base transceiver stations (BTSs) at the time of the test for future reference.

c. Set up the core router to mirror the VLAN 30 traffic to a spare port and monitor this port with a lap top computer running Wireshark.
d. Log into the first site Linksys switch using the console lap top in the core.
e. Disable the MLAT port 5 on the Linksys.
f. Use Wireshark captures of traffic at the MLAT port on the secure router that the MLAT traffic originating from that site stops.
g. Re-enable the port and watch the MLAT traffic resume. RECORD.
h. Repeat steps (c) through (f) for each of the active MLAT sensor sites.

B.1.3.2 QoS Traffic

Evaluate the effectiveness of QoS traffic differentiation through the use of the following types of data traffic streams:

a. One test traffic stream of random data generated by IxChariot as Best Effort (BE) QoS
b. One test traffic stream generated by IxChariot that emulates MLAT traffic as non-real-time poling service (nrtPS) QoS
c. Live MLAT traffic from all active MLAT sensor sites as nrtPS QoS

Measure total SS and BTS sector throughput capacity, packet integrity (dropped packets, out-of-order packets, or duplicate packets), and time latency as IxChariot BE traffic is increased to exceed the BTS sector throughput capacity.

a. Stop all sources of traffic that are not related to this test by closing ports on managed switches at the SS sites.
b. Survey connectivity to determine which SSs are connected to which BTSs at the time of the test.
c. Select a sector that has at least one SS that is a member of the high QoS group and one SS that is a member of a BE group.
d. Set up the IxChariot test script to run one throughput data pair, set to transmit data from the BE SS to the core on the uplink using TCP protocol.
e. Set a second IxChariot test script to run one throughput pair that emulates MLAT traffic; set up to transmit data from the nrtPS SS to the core on the uplink using TCP protocol.
f. Set the core router to mirror the VLAN 30 traffic to a spare port and monitor this port with a lap top computer running Wireshark.
g. Observe on the Wireshark captures the MLAT traffic packet integrity. RECORD.
h. Stop the IxChariot script and save the results.
i. Clone the data pair and launch the IxChariot script again.
j. Observe on the Wireshark captures the MLAT traffic packet integrity. RECORD.
k. Repeat steps (f) through (j) until the BTS sector capacity has been exceeded.

B.1.3.3 QoS MLAT Sensor Site

Verify that a high QoS MLAT sensor site can enter the AeroMACS network, authenticate, and transfer live traffic with the prescribed QoS in a sector that is saturated with IxChariot test traffic of lower priority. Perform the following:

a. Stop all sources of traffic that are not related to this test by closing ports on managed switches at the SS sites.
b. Survey connectivity to determine which SSs are connected to each BTSs at the time of the test.
c. Select a sector that has at least one SS that is a member of the high QoS group and one SS that is a member of a BE group.
d. Set the IxChariot test script to have at least 5 data pairs, each of which are set up to transmit data from the BE SS to the core on the uplink using TCP.

e. Monitor the MLAT traffic coming from the SS with high QoS using IxChariot.
f. Log into the SS that is generating the high QoS MLAT traffic.
g. Initiate a reset of this SS.
h. Monitor the MLAT traffic and observe the traffic dropoff when the SS resets and then resume as it comes the SS is reauthenticated in the network. RECORD.

B.1.3.4 10-MHz Channel Bandwidth

Option if time permits: repeat measurements with 10-MHz channel bandwidth.

B.1.3.5 AeroMACS Network

Demonstrate the ability for the AeroMACS network to carry sensor application traffic for additional applications as opportunities become available. Establish a new VLAN within AeroMACS for each application.

B.1.4 Test Documentation

Test results must be saved with the format defined in Section 5.0.

B.2 Test Case 2, AeroMACS Mobility Test

B.2.1 Purpose of Tests

A series of tests will evaluate the ability of a mobile AeroMACS SS to support communications under a variety of conditions and at minimal radiated power:

a. Mobile at speeds of at least 40 knots
b. Single-input, single output (SISO) and multiple input, multiple output (MIMO) modes
c. Omni antenna spacings of 2 to 10 wavelengths
d. 5- and 10-MHz channel bandwidths
e. Mobility across BS sector and BS regions requiring service handoff

B.2.2 AeroMACS Network Configuration

B.2.2.1 Physical Configuration

The network is to be operational with two multisector BSs, eight SSs, and an operating core network that includes backhaul links to a secure router and servers with AAA and NMS applications. The equipment that is available for this test case is listed in Section B.7.

A custom SS, modified with radiofrequency (RF) connectors for the use of external antennas, will be mounted in the NASA AeroMACS Research Vehicle (ARV) van. Two omnidirectional pattern antennas will be mounted on a metal plate on top of the van, and the custom SS will be mounted under the plate external to the van. The SS will be supported with an electronics enclosure inside the van that contains a network switch, a SS power supply, and a single-board computer (SBC) running a client of IxChariot software for test traffic generation. An Ethernet cable will run from the electronics enclosure the SS unit that provides a PoE signal and power connection.

B.2.2.2 Air Link and Network Configuration

The AeroMACS network will be configured according to the settings of Table 24 using Alepo AAA and Alvaristar NMS.

TABLE 24.—TEST CASE 2 AIR LINK AND NETWORK CONFIGURATION SETTINGS
[Acronyms are defined in Appendix A.]

AeroMACS parameter		Setting
AAA server		Enabled
PKMv2, EAP-TTLS security		Enabled
AES-128 air link encryption		Enabled
Maximum transmission unit (MTU) size		1440 bytes
DL/UL ratio		60/40
HARQ		Enabled
MIMO		Set per test plan
Channel bandwidth		Set per test plan
Quality of service (QoS)		Set per test plan
BTS center frequencies, MHz		
	BTS1-1	5095
	BTS1-2	5125
	BTS2-1	5105
	BTS2-2	5115
	BTS2-3	5100
BTS Tx Power, dBm		
	BTS1-1	21
	BTS1-2	21
	BTS2-1	21
	BTS2-2	21
	BTS2-3	21
SS UL RSSI, dBm		–50 to –75
SS UL CINR		> 14 dB
SS DL RSSI, dBm		–50 to –75
SS DL CINR		> 14 dBi
BTS firmware version		4.6.2.2/24848
SS firmware version		1.5.1.16
Alepo AAA version		7.2
Alvaristar NMS version		4.5.0.47.Patch
Device driver version		1.5.0.31.beta

B.2.2.3 Drive Path 2-1 Definition

Test vehicle will be parked on West Hangar road approximately beside the antenna tower adjacent to NASA Building 4 and facing south west. The drive path will be down West Hangar Road for approximately ½ mile where the road curves to the left and terminates at a building. This path is chosen primarily to test mobile performance within a single sector of a BS. It might be necessary to limit the SS frequency table to ensure it only communicates with BTS1-1.

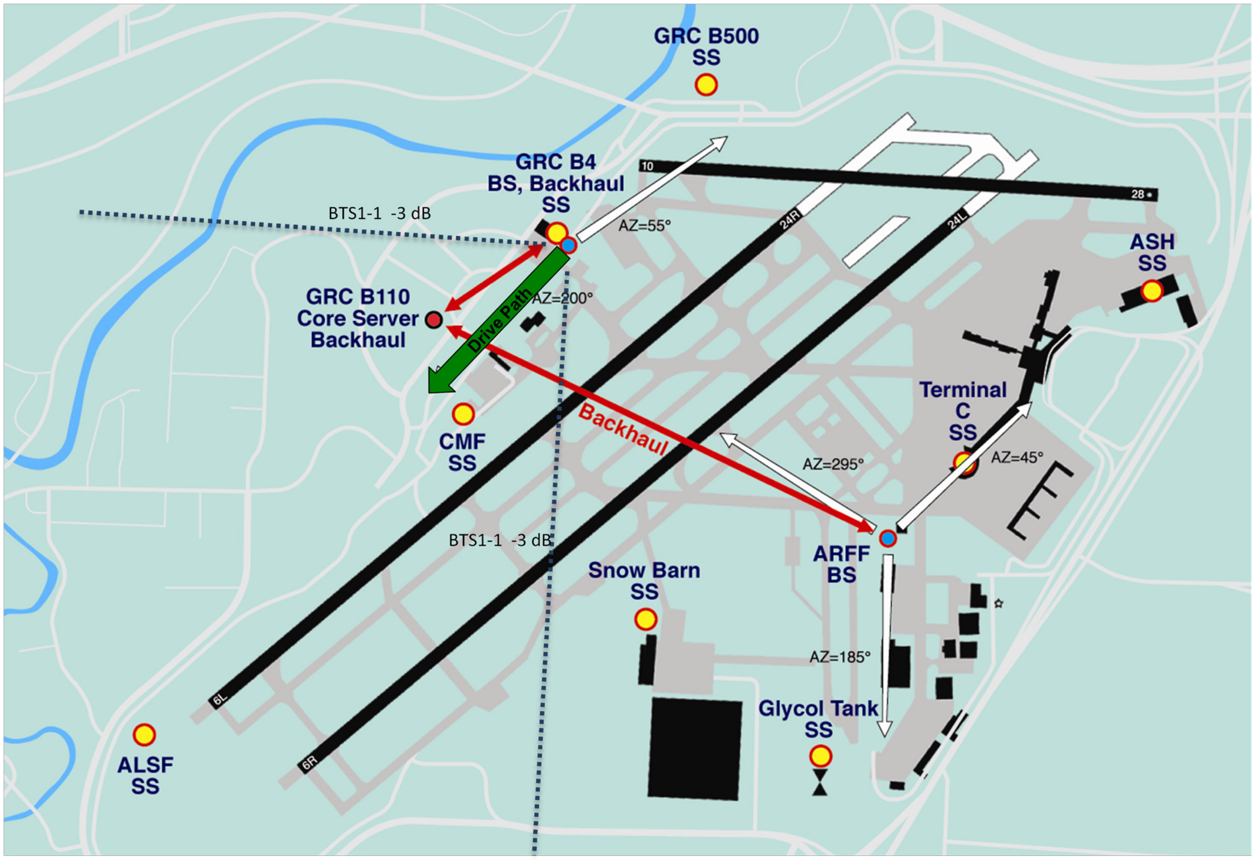


Figure 52.—Drive Path 2-1. Distance is 0.52 miles.

B.2.2.4 Drive Path 2-2 Definition

Test vehicle will be parked on West Hangar road facing West across from the traffic light at the B500 parking lot entrance. The drive path will be west and southwest past NASA B4 and down West Hangar road for approximately ½ mile where the road curves to the left and terminates at a building. The entire path is approximately 1 mile. This path has been selected to test mobile performance during a sector to sector handoff within a single base station. In this case the SS would first associate with BTS1-2 and then once it passes the tower, associate with BTS1-1. Again it might be necessary to limit the SS frequency table to ensure it does not try to associate with BTS2.

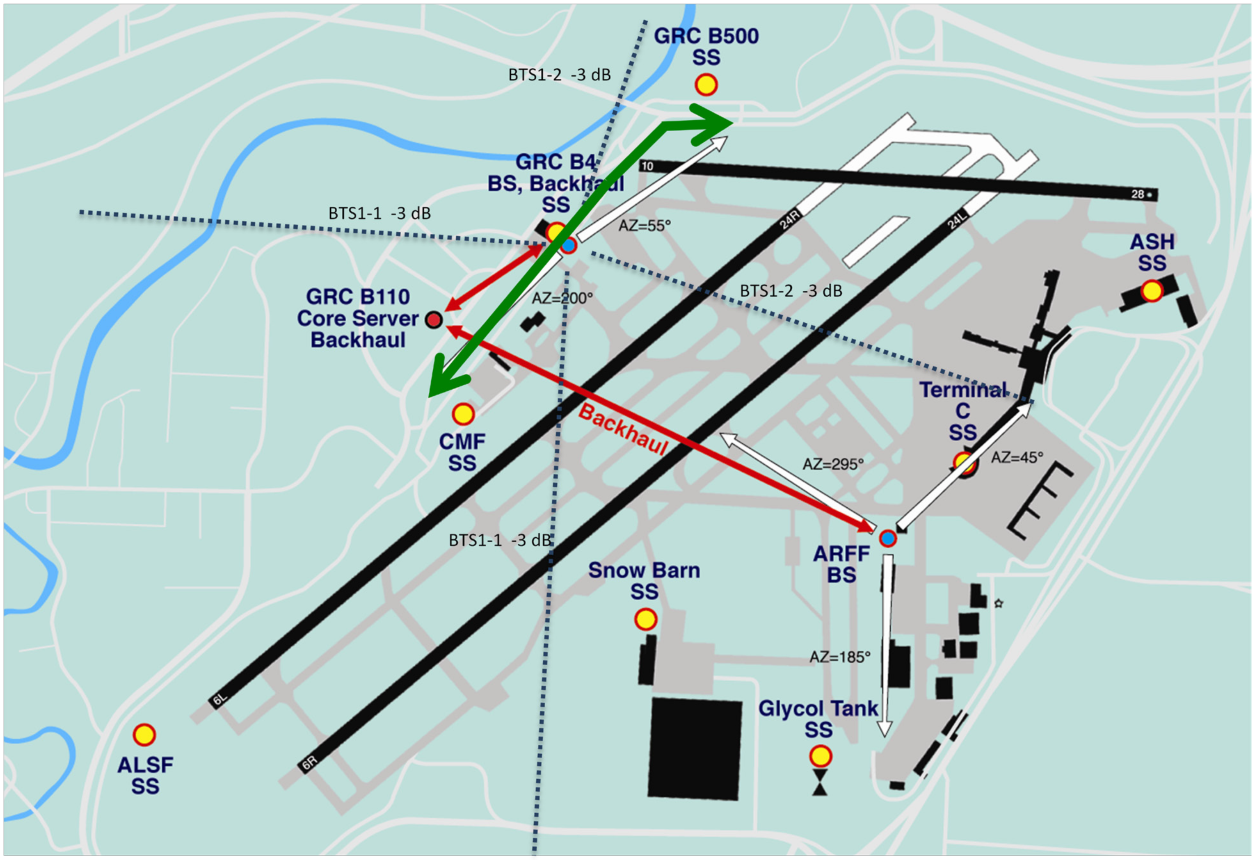


Figure 53.—Drive Path 2-2.

B.2.2.5 Drive Path 2-3 Definition

Test vehicle will be parked at the CLE Snow Barn (Site 4) and positioned to head southwest toward the ALSF site. The path (Grayton Road) will take the mobile test vehicle southwest and parallel to the runway/taxi way, around the southern end of the runway near the ASLF site 5 and then back north east past the CMF site 6. The vehicle will proceed to the point where tower clearance is required. At this point, the FAA escort will obtain tower clearance and the vehicle will then proceed on the taxiway until it gets to the point where it makes a 90-degree turn to the left. (This will lead to a gate that aircraft from NASA Building 4 use to enter the airport space.) The test vehicle will exit through this gate (making sure it closes behind it) and make a right turn onto West Hangar road. The test vehicle will then proceed north/northeast on this road until it reaches the Airport Service Hangar area (formerly referred to as the GA Hangar). At this point the test vehicle will stop and turn around to prepare for the return trip. This path has been selected to test mobile performance during a sector to sector handoff between two base stations. In this case, the SS should at first be associated with BTS2-X (the same sector that the snow barn SS is associated with). It is expected that at some point after it makes the turn and is heading northeast, it will associate with BTS1-2. Again it might be necessary to limit the SS frequency table.

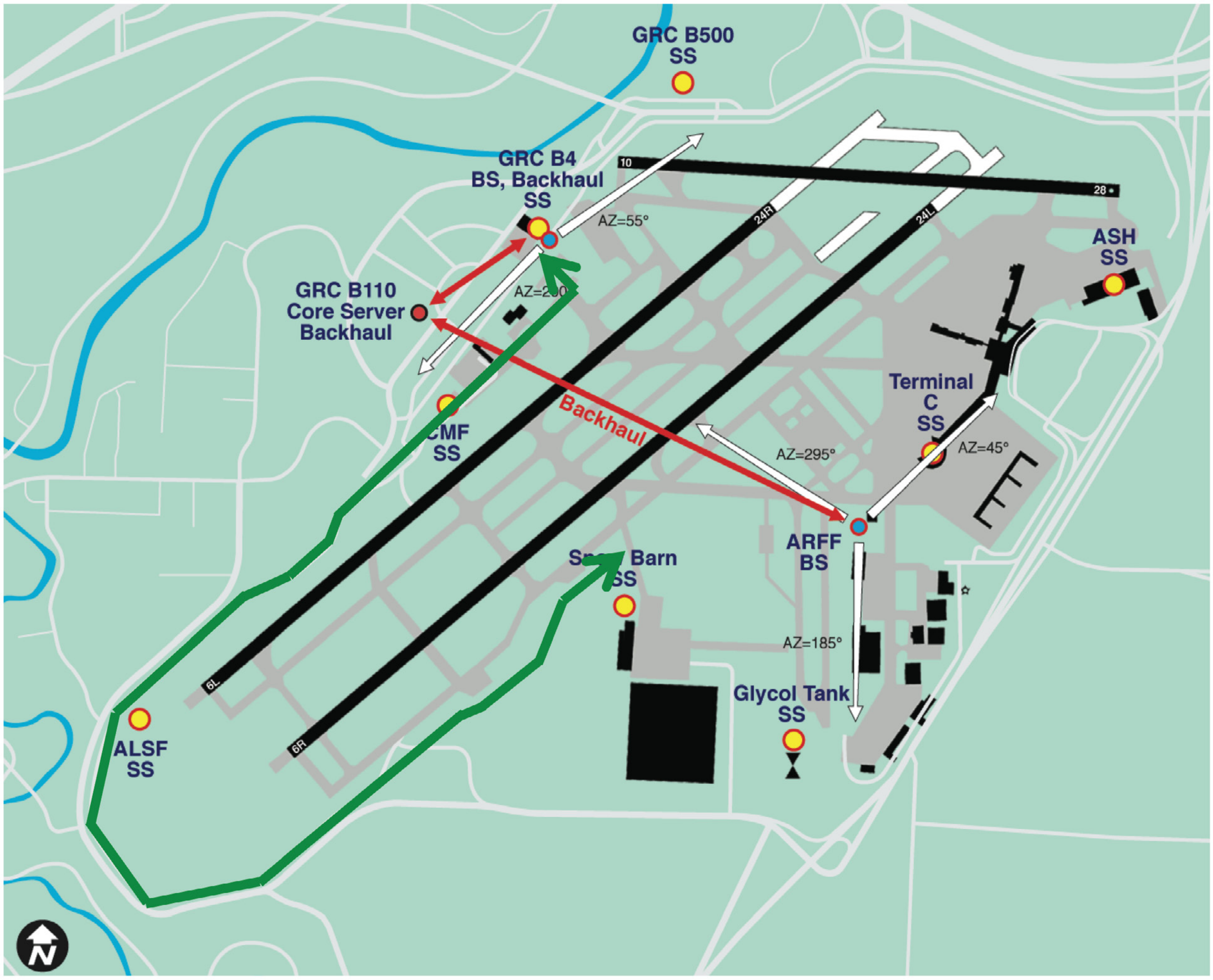


Figure 54.—Drive Path 2-3.

B.2.2.6 Unique Prerequisites

In addition to the criteria specified, the following criteria must be met before executing this test case.

a. YellowFin analyzer loaded with a projection file of the planned route the vehicle will be traveling during the test
b. Console computer IxChariot loaded with Response Time Script
c. Vehicle generator fuel tank with sufficient fuel to run 4 hr
d. At least two orange traffic cones onboard for roadside stops

B.2.3 Procedure

The matrix of tests defined in Table 25 will be completed.

TABLE 25.—TEST CASE 2 MOBILE TEST CONDITIONS
[Acronyms are defined in Appendix A.]

Test no.	Vehicle speed, knots (kt)	Vehicle speed, km/hr (KPH)	Vehicle speed, mi/hr (MPH)	SS adaptive antenna (BS remain 2×2 MIMO)	Antenna spacing, wavelengths	Channel bandwidth, MHz	Drive path	Other conditions
2.1	10	19	12	SISO		5	2-1	
2.2	20	37	24	SISO		5	2-1	
2.3	30	56	35	SISO		5	2-1	
2.4	40	74	46	SISO		5	2-1	
2.5	20	37	24	2×1 MIMO	10	5	2-1	
2.6	40	74	46	2×1 MIMO	10	5	2-1	
2.7	20	37	24	2×1 MIMO	1	5	2-1	
2.8	40	74	46	2×1 MIMO	1	5	2-1	
2.9	20	37	24	2×1 MIMO		10	2-1	
2.10	40	74	46	2×1 MIMO		10	2-1	
2.11	20	37	24	2×1 MIMO		10	2-1	
2.12	40	74	46	2×1 MIMO		10	2-1	
2.13	20	37	24	2×1 MIMO		5	2-2	Path between sectors
2.14	40	74	46	2×1 MIMO		5	2-3	Path between BS
2.15	0	0	0	2×1 MIMO		0	N/A	Stationary NLOS
2.16	20	37	24	2×1 MIMO		5	TBD	Mobile into NLOS

Parameters to measure and record with GPS position information include

(a) RSSI
(b) CINR
(c) SS throughput
(d) Packet integrity
(e) Packet latency and jitter

a. Stop all sources of traffic that are not related to this test by closing ports on managed switches at the SS sites.
b. From the core, survey all SS to BTS associations using Alvaristar. RECORD.
c. Log into the mobile SS and RECORD the BST/AU table.
d. Synchronize the console laptop time-of-day clock with the YellowFin instrument as the reference to within 1 s.
e. At B110 Core, launch the IxChariot response time script for a 1-min test to ensure connectivity with the mobile SS. RECORD results. If successful, communicate to the mobile test team that they should start accelerating.
f. At B110 Core, launch the IxChariot Response Time Script for a minimum 5-min test. Inform the SS that IxChariot has started and they can launch the Yellow Fin analyzer collection.
g. In the mobile van, Start YellowFin analyzer Dragnet Collector logging program with the YellowFin in the Spectrum Analyzer mode.
h. Verify that the YellowFin is set a channel bandwidth that matches base station transmissions.
i. Verify that YellowFin GPS is locked to satellites.

j. Record time of day and accelerate vehicle up to test speed and hold as constant as road conditions will permit. Drive the planned route and then pull over to a safe stopping location to save the data.
k. Record time of day for end of run.
l. Stop the YellowFin data collection and save the file.
m. At B110 Core, wait until the IxChariot test has completed (if it has not already) and save the results in the appropriate folder.
n. Turn the test vehicle around for the return trip test. Inform the core team you are ready for the return trip.
o. At B110 Core, launch the IxChariot response time script for a minimum 5-min test. Inform the mobile van team that IxChariot has started and they can launch the YellowFin analyzer collection and start driving.
p. In the mobile van, start the YellowFin analyzer collection program.
q. Accelerate vehicle up to test speed and hold as constant as road conditions will permit. Drive the planned route at the constant speed and then decelerate to a stop. Inform the B110 Core team that you have stopped and they can save their data.
r. Stop the YellowFin data collection and save the file. Inform B110 Core that you have stopped.
s. At B110 Core, wait until the IxChariot test has completed (if it has not already) and save the results in the appropriate folder. This completes the test.
t. Repeat the procedure starting at step (d) above for all tests while changing the parameter defined in the test matrix in Table 25.

B.2.4 Test Documentation

Test results must be saved with the format defined in Section 5.0.

B.3 Test Case 3, Channelization

B.3.1 Purpose of Tests

The results of these tests will support the development of a methodology for assigning channel bandwidth within the 5091- to 5150-MHz AM(R)S band with possible expansion to 5000- to 5030-MHz. The results from these adjacent channel test results will be combined with results of drive tests to make recommendations for airport channelization strategies.

B.3.2 AeroMACS Network Configuration

B.3.2.1 Physical Configuration

The network is to be operational with two multisector BSs, eight SSs, and a core network operational that includes backhaul links to a secure router and servers with AAA and NMS applications. The equipment that is available for this test case is listed in Section B.7.

B.3.2.2 Air Link and Network Configuration

The AeroMACS network will be configured according to the settings of Table 26 and Table 27 using Alepo AAA and Alvaristar NMS.

TABLE 26.—TEST CASE 3 AIR LINK AND NETWORK CONFIGURATION SETTINGS, 5-MHZ CHANNELIZATION TESTS
[Acronyms are defined in Appendix A.]

AeroMACS parameter		Setting
AAA server		Enabled
PKMv2, EAP-TTLS security		Enabled
AES-128 air link encryption		Enabled
Maximum transmission unit (MTU) size		1440 bytes
DL/UL ratio		60/40
HARQ		Set per test plan
MIMO		Mode A
Channel bandwidth		Set per test plan
Quality of service (QoS)		BE
BTS center frequencies, MHz		
	BTS1-1	5095
	BTS1-2	5125
	BTS2-1	5105
	BTS2-2	5115
	BTS2-3	5100
BTS Tx pwer, dBm		
	BTS1-1	21
	BTS1-2	21
	BTS2-1	21
	BTS2-2	21
	BTS2-3	21
SS UL RSSI, dBm		–50 to –75
SS UL CINR		> 14 dB
SS DL RSSI, dBm		–50 to –75
SS DL CINR		> 14 dBi
BTS firmware version		4.6.2.2/24848
SS firmware version		1.5.1.16
Alepo AAA version		7.2
Alvaristar NMS version		4.5.0.47.Patch
Device driver version		1.5.0.31.beta

TABLE 27.—TEST CASE 3 AIR LINK AND NETWORK CONFIGURATION SETTINGS, 10-MHZ CHANNELIZATION TESTS
[Acronyms are defined in Appendix A.]

AeroMACS parameter		Setting
AAA server		Enabled
PKMv2, EAP-TTLS security		Enabled
AES-128 air link encryption		Enabled
Maximum transmission unit (MTU) size		1440 bytes
DL/UL ratio		60/40
HARQ		Set per test plan
MIMO		Enabled
Channel bandwidth		Set per test plan
Quality of Service (QoS)		BE
BTS center frequencies, MHz		
	BTS1-1	5100
	BTS1-2	5140
	BTS2-1	5130
	BTS2-2	5120
	BTS2-3	5110
BTS Tx power, dBm		
	BTS1-1	21
	BTS1-2	21
	BTS2-1	21
	BTS2-2	21
	BTS2-3	21
SS UL RSSI, dBm		–50 to –75
SS UL CINR		> 14 dB
SS DL RSSI, dBm		–50 to –75
SS DL CINR		> 14 dBi
BTS firmware version		4.6.2.2/24848
SS firmware version		1.5.1.16
Alepo AAA version		7.2
Alvaristar NMS version		4.5.0.47.patch
Device driver version		1.5.0.31.beta

B.3.3 Test Procedure

a. Stop all sources of traffic that are not related to this test by closing ports on managed switches at the SS sites.
b. From the core, log into Alvaristar and survey all SS to BTS associations using Alvaristar. RECORD.
c. Choose a fixed-site SS near the crossover point between two BS sectors having adjacent frequency channels. (This will most likely be two that are associated with BTS2.) Use IxChariot to establish a downlink (BS to SS) UDP data flow that utilizes the maximum data bandwidth capability of the SS. Record throughput and packet integrity statistics.
d. Choose a second fixed-site SS that is associated with the adjacent BS sector. Use IxChariot to establish a downlink (BS to SS) UDP data flow that utilizes the maximum data bandwidth capability of the second SS. Set the IxChariot script for a startup delay of 60 s. Record throughput and packet integrity statistics for both data flows. Save the results and export the html and csv files.

e. Repeat steps (a) and (b) with traffic in the uplink (SS to BS) direction.
f. Repeat steps (a) and (b) with traffic in both the uplink and downlink directions (duplex operation).
g. Repeat steps (a) and (b) with traffic in the uplink direction using 10-MHz channel bandwidths

B.3.4 Test Documentation

Test results must be saved with the format defined in Section 5.0.

B.4 Test Case 4, Tx Power

B.4.1 Purpose of Tests

The results of these tests will be used to set recommendations for BS and SS transmit power levels that will provide communication coverage across an airport surface while also minimizing potential interference to co-users of the AM(R)S band. The transmit power level requirements will be established through a series of tests with stationary and mobile SSs.

B.4.2 AeroMACS Network Configuration

B.4.2.1 Physical Configuration

The network is to be operational with two multisector BSs, eight SSs, and a core network operational that includes backhaul links to a secure router and servers with AAA and NMS applications. The equipment that is available for this test case is listed in Section B.7.

B.4.2.2 Air Link and Network Configuration

The AeroMACS network will be configured according to the settings of Table 28 using Alepo AAA and Alvaristar NMS.

TABLE 28.—TEST CASE 3 AIR LINK AND NETWORK CONFIGURATION SETTINGS, 5-MHZ CHANNELIZATION TESTS
[Acronyms are defined in Appendix A.]

AeroMACS parameter		Setting
AAA server		Enabled
PKMv2, EAP-TTLS security		Enabled
AES-128 air link encryption		Enabled
Maximum transmission unit (MTU) size		1440 bytes
DL/UL ratio		60/40
HARQ		Enabled
MIMO		Mode A
Channel bandwidth		5 MHz
Quality of service (QoS)		BE
BTS center frequencies, MHz		
	BTS1-1	5095
	BTS1-2	5145
	BTS2-1	5105
	BTS2-2	5115
	BTS2-3	5100
BTS Tx power, dBm		
	BTS1-1	≤21
	BTS1-2	≤21
	BTS2-1	≤21
	BTS2-2	≤21
	BTS2-3	≤21
SS UL RSSI, dBm		–50 to –75
SS UL CINR		> 14 dB
SS DL RSSI, dBm		–50 to –75
SS DL CINR		> 14 dBi
BTS firmware version		4.6.2.2/24848
SS firmware version		1.5.1.16
Alepo AAA version		7.2
Alvaristar NMS version		4.5.0.47.patch
Device driver version		1.5.0.31.beta

B.4.2.3 Drive Path 4-1 Definition

Test vehicle will enter the airport perimeter at the entrance gate near the Airport Service Hangar (formerly referred to as the GA Hangar). The drive path will be to the west around Concourse A, staying as close as possible to the Concourse gates and parked aircraft as shown in Figure 55. After rounding the end of Concourse A, the test vehicle will proceed to follow the contour of the Concourse to the apex or intersection of Concourses A and B. From there, the test vehicle will follow a similar path around Concourses B and C. Once finished with Concourse C, the test vehicle will turn to the right (east) and proceed to Concourse D. The vehicle will then proceed down the west side of D (the side facing C) and then back up the east side. Once finished with D, the test vehicle will exit the airport perimeter and drive in the area behind the post office/FedEx buildings. The vehicle will then exit this area onto Cargo Road and turn right onto the road that runs past the glycol tanks. The test vehicle will proceed to the snow barn where the test will end. This path has been selected to test the RF coverage of the system in and around the terminal area.

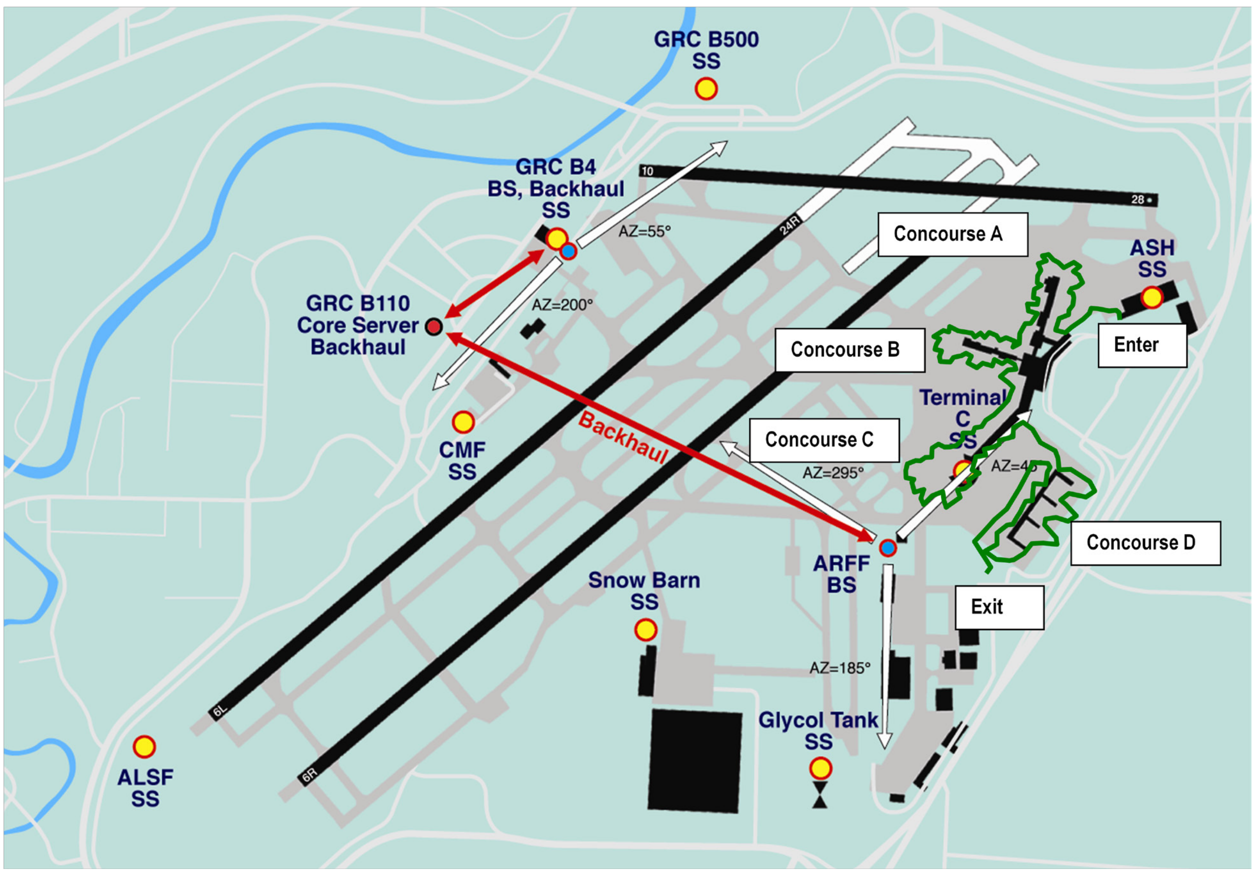


Figure 55.—Drive Path 4-1.

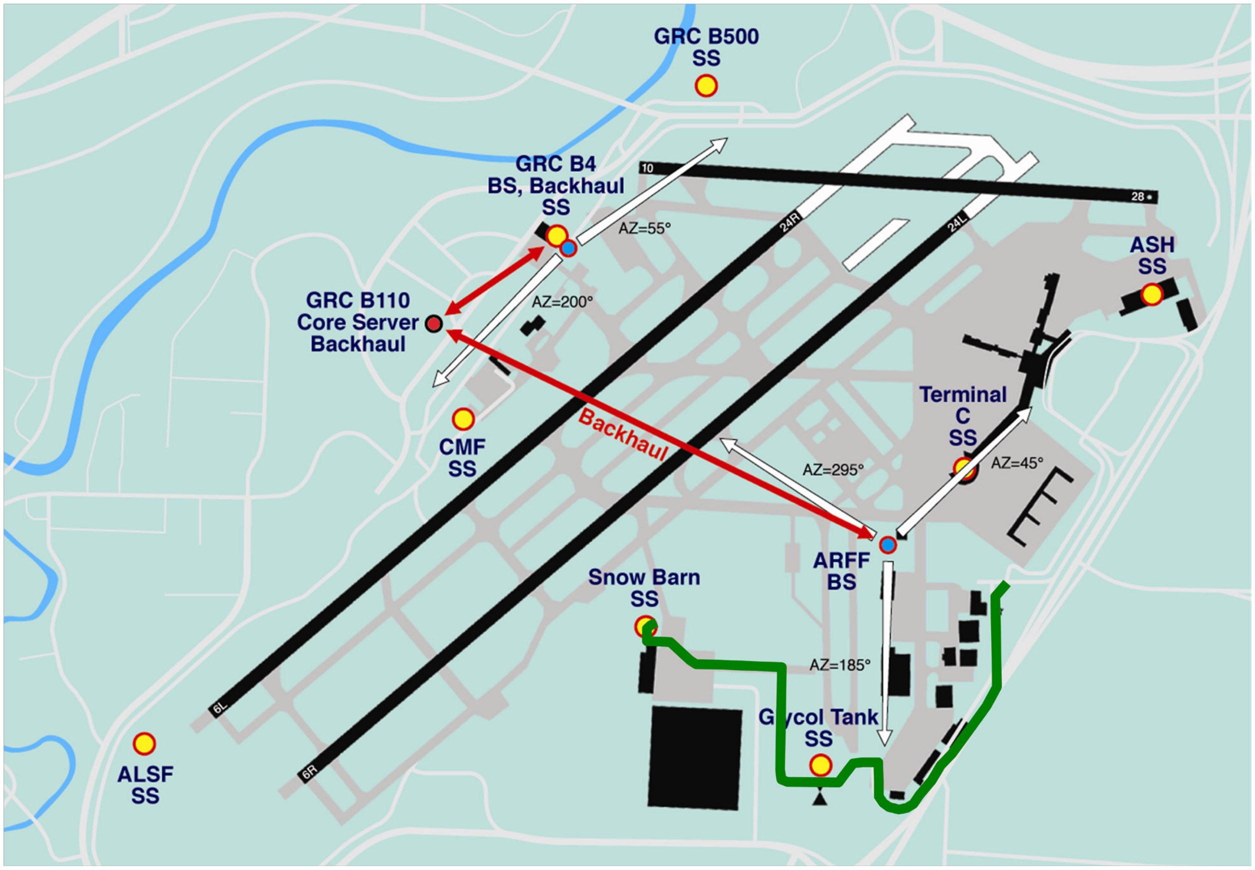


Figure 56.—Drive Path 4-1 continued.

B.5 Test Case 4 Unique Prerequisite

Drive Path 4-1 includes driving the NASA ARV van across active airport areas, see Figure 56. This will require escort by someone with the correct training and credentials from either the FAA or the Cleveland Hopkins Port Authority.

B.5.1 Test Procedure

a. Stop all sources of traffic that are not related to this test by closing ports on managed switches at the SS sites.
b. At B110 core, survey all SS to BTS associations using Alvaristar. RECORD
c. In the ARV, power up the YellowFin analyzer and load the appropriate map for the drive path.
d. Load the frequency table into the YellowFin.
e. At the B110 core, log into the mobile SS and RECORD the BST/AU table.
f. At B110 Core, launch the IxChariot response time script for a 1-min test to ensure connectivity with the mobile SS. RECORD results. If successful, communicate to the mobile test team that they should proceed to the security checkpoint.
g. In the ARV, once through the security check point the mobile team should inform the B110 Core team that they are ready to start the test run.
h. At B110 Core, launch the IxChariot Response Time Script for a minimum TBD minute test. Inform the SS that IxChariot has started and they can launch the YellowFin analyzer collection.
i. In the mobile van, start YellowFin analyzer Dragnet Collector logging program with the YellowFin in the Spectrum Analyzer mode.

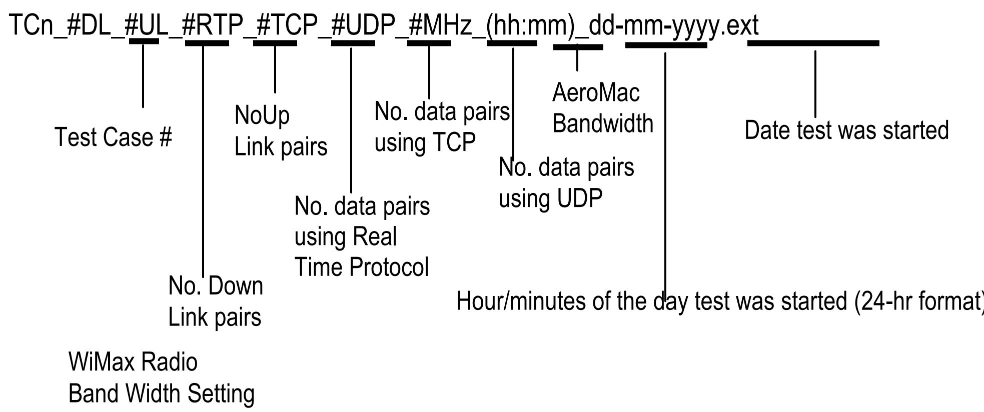
j. Verify that the YellowFin is set a channel bandwidth that matches base station transmissions.
k. Verify that YellowFin GPS is locked to satellites.
l. Start the vehicle on the drive path, at a speed that terminal conditions and safety will permit. Drive the planned route and then pull over to a safe stopping location to save the data.
m. Stop the YellowFin data collection and save the file.
n. At B110 Core, wait until the IxChariot test has completed (if it has not already) and save the results in the appropriate folder. This will end the test.
o. Repeat the procedure starting at step (d) above for all tests while changing the parameters defined in Table 26.

B.5.2 Test Documentation

Test results must be saved with the format defined in Section 5.0.

B.6 IxChariot Results

IxChariot results should be recorded saved with the following format for all tests:



Example:
TC1_2DL_1UL_0RTP_3TCP_0UDP_5MHz_(13:10)_05_05_2010.html

Reads: Test Case 1, two downlink pairs, one uplink pair, none using RTP, 3 using TCP, none using UDP. AeroMACS set to 5MHz bandwidth, test start at 13:10 on 5 May 2010.

B.7 Equipment Lists

TABLE 29.—EQUIPMENT LIST
[Acronyms are defined in Appendix A.]

Item	ASH	Item no. (Master)	Description	Mfg.	Model	SN/Version
1	1	325-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975779000
2	1	325-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:c0
3	1	325-1-1-1	Compact flash memory 2GB Industrial CF	Transcend	HV4719	None
4	1	325-1-1-1a	Software	Open source	Linux Slackware	V10
5	1	325-1-1-1b	Software—Endpoint Client for IxChariot for x86 32 bit	Ixia	TBD	N/A
6	1	325-1-3	5-port industrial Ethernet-managed data switch	Sixnet	SLX-5MS	
7	1	325-1-11	Power Supply for AeroMacs ODU	Alvarion	PS1065	A30912119795
8	1	325-2	AeroMacs ODU	Alvarion	Extreme 5000	7861398
9	1	325-2-1	Software	Alvarion	N/A	1.5.1.16
	CTerm					
10	2	451-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975784000
11	2	451-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:ca
12	2	451-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
13	2	451-1-1-1a	Software	Open source	Linux Slackware	V10
14	2	451-1-1-1b	Software—Endpoint Client for IxChariot for x86 32 bit	Ixia	TBD	N/A
15	2	451-13	5-port industrial Ethernet-managed data switch	Sixnet	TBD	MAC: 00:24:98:1a:f4:5e
16	2	451-1-11	Power supply for AeroMacs ODU	Alvarion	PS1065	A30912119780
17	2	451-2	AeroMacs ODU	Alvarion	Extreme 5000	7861395
18	2	451-2-1	Software	Alvarion	N/A	1.5.1.16

TABLE 30.—EQUIPMENT LIST (SITES 1 AND 2)
[Acronyms are defined in Appendix A.]

Item	Glycol	Item no. (Master)	Description	Mfg.	Model	SN/Version
19	3	401-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975782000
20	3	401-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:c2
21	3	401-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
22	3	401-1-1-1a	Software	Open source	Linux Slackware	V10
23	3	401-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
24	3	401-1-3	5-port industrial Ethernet-managed data switch	Sixnet	SLM2005	MAC: 00:24:98:1a:f3:b6
25	3	401-1-11	Power supply for AeroMacs ODU	Alvarion	PS1065	A30912119778
26	3	401-2	AeroMacs ODU	Alvarion	Extreme 5000	7861394
27	3	401-2-1	Software	Alvarion	N/A	V1.5.1.16
	SBarn					
28	4	375-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975776000
29	4	375-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:d4
30	4	375-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
31	4	375-1-1-1a	Software	Open source	Linux Slackware	V10
32	4	375-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
33	4	375-13	5-port industrial Ethernet-managed data switch	Sixnet	TBD	MAC: 00:24:98:1a:f3:4e
34	4	375-1-11	Power supply for AeroMacs ODU	Alvarion	PS1065	A30912119759
35	4	375-2	AeroMacs ODU	Alvarion	Extreme 5000	7861390
36	4	375-2-1	Software	Alvarion	N/A	1.5.1.16

TABLE 31.—EQUIPMENT LIST (SITES 3 AND 4)
[Acronyms are defined in Appendix A.]

Item	ALSF	Item no. (Master)	Description	Mfg.	Model	SN/Version
37	5	426-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975777000
38	5	426-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:d6
39	5	426-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
40	5	426-1-1-1a	Software	Open source	Linux Slackware	V10
41	5	426-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
42	5	426-1-3	5-port industrial Ethernet-managed data switch	Sixnet	SLM2005	MAC: 00:24:98:1a:f3:e6
43	5	426-1-11	Power dupply for AeroMacs ODU	Alvarion	PS1065	A30912119775
44	5	426-2	AeroMacs ODU	Alvarion	Extreme 5000	7861405
45	5	426-2-1	Software	Alvarion	N/A	V1.5.1.16
	CMF					
46	6	350-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975018000
47	6	350-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:c4
48	6	350-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
49	6	350-1-1-1a	Software	Open source	Linux Slackware	V10
50	6	350-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
51	6	350-13	5-port industrial Ethernet-managed data switch	Sixnet	TBD	MAC: 00:24:98:1a:ef:9e
52	6	350-1-11	Power supply for AeroMacs ODU	Alvarion	PS1065	A30912119763
53	6	350-2	AeroMacs ODU	Alvarion	Extreme 5000	7861412
54	6	350-2-1	Software	Alvarion	N/A	1.5.1.16

TABLE 32.—EQUIPMENT LIST (SITES 5 AND 6)
[Acronyms are defined in Appendix A.]

Item	B4 (roof)	Item no. (Master)	Description	Mfg.	Model	SN/Version
55	7	203-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975775000
56	7	203-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:d1
57	7	203-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
58	7	203-1-1-1a	Software	Open Source	Linux Slackware	V10
59	7	203-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
60	7	203-1-3	5-port industrial Ethernet-managed data switch	Sixnet	SLM2005	MAC: 00:24:98:1a:e9:7e
61	7	203-1-11	Power supply for AeroMacs ODU	Alvarion	PS1065	No tag
62	7	203-2	AeroMacs ODU	Alvarion	Extreme 5000	7865990
63	7	203-2-1	Software	Alvarion	N/A	V1.5.1.16
	B500					
64	8	301-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	9975017000
65	8	301-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:da
66	8	301-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
67	8	301-1-1-1a	Software	Open source	Linux Slackware	V10
68	8	301-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
69	8	301-1-3	5-port industrial Ethernet-managed data switch	Sixnet	TBD	MAC: 00:24:98:1a:f0:8e
70	8	301-1-11	Power supply for AeroMacs ODU	Linksys	SLM2005	TBD
71	8	301-2	AeroMacs ODU	Alvarion	Extreme 5000	7861374
72	8	301-2-1	Software	Alvarion	N/A	1.5.1.16

TABLE 33.—EQUIPMENT LIST (SITES 7 AND 8)
[Acronyms are defined in Appendix A.]

Item	ARFF (inside)	Item no. (Master)	Description	Mfg.	Model	SN/Version
73	9	101-1	Cabinet			9985487000
74	9	101-1	Lambda PS rack	Lambda	THR4	082887100937
75	9	101-1-1	Lambda PS module	Lambda	TH200048	TBD
76	9	101-5	Backhaul IDU	Ceragon	TBD	9980030000
77	9	101-9	PS for BTS ODU (–55v,1.27A)	Alvarion	0525B5570	No Tag
78	9	101-10	PS for BTS ODU (–55v,1.27A)	Alvarion	0525B5570	No Tag
79	9	101-11	PS for BTS ODU (–55v,1.27A)	Alvarion	0525B5570	No Tag
80	9	101-14	SBC enclosure	ITT	n/a	No tag
81	9	101-14-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:d1
82	9	101-14-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
83	9	101-14-1-1a	Software	Open Source	Linux Slackware	V10.0
84	9	101-14-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
85	9	101-18	Data switch	Avaya/Nortel	Baystack 470-48T	TBD
86	9	102-1	Backhaul cable	--	LMR400	No tag
87	9	102-2	Backhaul ODU	Ceragon	15P-OX-11-L-TL	TBD
88	9	102-3	AeroMacs BTS2-1	Alvarion	9985527000	00:10:e7:e2:57:1a
89	9	102-4	AeroMacsBTS2-2	Alvarion	9985525000	00:10:e7:e2:57:1c
90	9	102-5	AeroMacsBTS2-3	Alvarion	9985526000	00:10:e7:e2:56:91
91	9	102-6	2-ft dish antenna for backhaul	RadioWaves	HP-11G	24332
92	9	102-10	Ballast roof mount	Tessco	48544	9981055000
93	9	102-11	POE surge suppressors	Transtector	ALPV-ALVR	No tag
94	9	102-12	POE surge suppressors	Transtector	ALPV-ALVR	No tag
95	9	102-13	POE surge suppressors	Transtector	ALPV-ALVR	No tag
96	9	102-14	GPS receiver	TBD	TBD	TBD
97	9	102-15	GPS receiver	TBD	TBD	TBD
98	9	102-16	GPS receiver	TBD	TBD	TBD

TABLE 34.—EQUIPMENT LIST (SITE 9)
[Acronyms are defined in Appendix A.]

Item	B110 (inside)	Item no. (Master)	Description	Mfg.	Model	SN/Version
99	10	1-1	Core equipment cabinet			9981037000
100	10	1-1-5	Lambda PS rack	Lambda	TH4	No tag
101	10	1-1-5-1	Lambda PS module—48Vdc	Lambda	TH120048	9985778000
102	10	1-1-5-2	Lambda PS module—48Vdc	Lambda	TH120048	9985778000
103	10	1-1-8	Avaya router	Avaya	ERS5600	TBD
104	10	1-1-9	Server hardware	Microsoft	TBD	TBD
105	10	1-1-9-1	Software—Alepo AAA	Alepo	16e AAA Server w/IPAM	License no. 42000926
106	10	1-1-9-2a	Software—Alvaristar	Alvarion	Infrastructure (NMS Core)	V4.5.0.47.patch
106b	10	1-1-9-2b	Software—Alvaristar	Alvarion	BreezeMAX Extreme Device Driver (1.5 Extreme	V1.5.0.31.Beta
107	10	1-1-10	Server hardware		TBD	TBD
108	10	1-1-10-1	Software—Alvaricraft	Alvarion	TBD	TBD
109	10	1-1-12	Backhaul #2 IDU	Ceragon	1500P	TBD
110	10	1-1-13	Backhaul #1 IDU	Trango	Tlink-Giga-11	8280219
111	10	1-1-14	Data switch	Cisco	SD-216	TBD
112	10	1-1-15	LAP Top Computer	Dell	TBD	2005192000
113	10	1-1-15-1	Software—IxChariot Console	Ixia	TBD	TBD
114	10	1-1-22	SBC enclosure	ITT	N/A	No tag
115	10	1-1-22-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:d1
116	10	1-1-22-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
117	10	1-1-22-1-1a	Software	Open Source	Linux Slackware	V10.0
118	10	1-1-22-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	TBD	N/A
119	10	1-1-26	Spare AeroMacs ODU	Alvarion	XTRM-SU-0D-1D-4.9-UL-A 950307 Radio Remote SN 7861407	Tagged as NASA property
120	10	2-1	2-ft dish antenna for backhaul BH1	RadioWaves	A-2-11-A	TBD
121	10	2-2	2-ft dish antenna for backhaul BH2	RadioWaves	A-2-11-A	TBD
122	10	2-3	Backhaul ODU	Ceragon	15P-OX-11-L-TL	9980032000
123	10	2-4	Backhaul ODU	Trango	Tlink-Giga-11	9975259000
124	10	2-5	RF cable from BH1 IDU to BH1 ODU		LMR400	
125		2-6	RF cable from BH2 IDU to BH2 ODU		LMR400	
126		2-7	Backhaul mono pole assembly	Tessco		9981055000

Item	B110 (inside)	Item no. (Master)	Description	Mfg.	Model	SN/Version
	ARV1					
127	11	601-1	Weatherproof enclosure	HyperLink Technologies	NB141207-1HF	997578000
128	11	601-1-1	SBC	Octagon	2050-PC-104	MAC: 00:20:0b:01:5a:xx
129	11	601-1-1-1	Compact flash memory 2GB industrial CF	Transcend	HV4719	None
130	11	601-1-1-1a	Software—OS	Open source	Linux Slackware	V10.0
131	11	601-1-1-1b	Software—Endpoint client for IxChariot for x86 32 bit	Ixia	X86	N/A
132	11	601-1-11	Power Supply for AeroMacs SS ODU	Alvarion	PS1065	1234565000
133	11	601-2	AeroMacs ODU	Alvarion	Extreme 5000	9998010000
134	11	601-2-1	Software	Alvarion	N/A	1.5.1.16
135	11	601-6	Antenna A	Huber-Suhner	SWA2459/360/20/V_2	Marked #1
136	11	601-7	Antenna B	Huber-Suhner	SWA2459/360/20/V_2	Marked #2
137	11	601-8	YellowFin mobile WiMAX	Berkeley Varitronics	YellowFin PN0093-T-WY	SN300909

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14. ABSTRACT This report is provided as part of ITT's NASA Glenn Research Center Aerospace Communication Systems Technical Support (ACSTS) contract NNC05CA85C, Task 7: "New ATM Requirements-Future Communications, C-Band and L-Band Communications Standard Development" and was based on direction provided by FAA project-level agreements for "New ATM Requirements-Future Communications." Task 7 included two subtasks. Subtask 7-1 addressed C-band (5091- to 5150-MHz) airport surface data communications standards development, systems engineering, test bed and prototype development, and tests and demonstrations to establish operational capability for the Aeronautical Mobile Airport Communications System (AeroMACS). Subtask 7-2 focused on systems engineering and development support of the L-band digital aeronautical communications system (L-DACS). Subtask 7-1 consisted of two phases. Phase I included development of AeroMACS concepts of use, requirements, architecture, and initial high-level safety risk assessment. Phase II builds on Phase I results and is presented in two volumes. Volume I is devoted to concepts of use, system requirements, and architecture, including AeroMACS design considerations. Volume II (this document) describes an AeroMACS prototype evaluation and presents final AeroMACS recommendations. This report also describes airport categorization and channelization methodologies. The purposes of the airport categorization task were (1) to facilitate initial AeroMACS architecture designs and enable budgetary projections by creating a set of airport categories based on common airport characteristics and design objectives, and (2) to offer high-level guidance to potential AeroMACS technology and policy development sponsors and service providers. A channelization plan methodology was developed because a common global methodology is needed to assure seamless interoperability among diverse AeroMACS services potentially supplied by multiple service providers.					
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